CICLAGEM BIOGEOQUÍMICA E MODELAGEM DE BIOMASSA E NUTRIENTES EM POVOAMENTO DE EUCALIPTO EM SOLO DO CERRADO

MARCO BRUNO XAVIER VALADÃO

TESE DE DOUTORADO EM CIÊNCIAS FLORESTAIS
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"Tanto o solo quanto a água pertencem à biosfera, à ordem da natureza, e – como uma espécie entre muitas, como uma geração entre muitas que ainda estão por vir – não temos o direito de destruí-los. "

Daniel Hillel, Out of Earth

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RESUMO GERAL

O estudo ciclagem de nutrientes em povoamento de eucalipto em solo do Cerrado foi o tema principal do documento de tese de doutorado. O estudo foi conduzido na Fazenda Água Limpa – FAL, a qual pertence à Universidade de Brasília - UnB, situada no Distrito Federal. O povoamento selecionado apresentava área total de 3,29 ha e foi estabelecido em janeiro de 2010. O plantio do clone I224, híbrido de *Eucalyptus urophylla* S.T. Blake x *Eucalyptus grandis* Hill ex-Maiden foi realizado em espaçamento 3 x 2 m. O solo do plantio foi descrito como um Latossolo Vermelho de baixa fertilidade. Por meio da análise de parâmetros como a produção e acúmulo de serapilheira, decomposição foliar, química e física do solo e modelagem de nutrientes foi possível compreender a relevância da quantidade e qualidade dos resíduos orgânicos em povoamentos florestais. No primeiro capítulo foi possível constatar a alta produção e acúmulo de serapilheira em povoamento de eucalipto, porém com uma decomposição mais lenta. No segundo, verificou-se que a remoção da camada de serapilheira do solo acarretou em aumento no tempo estimado de decomposição foliar, alterou a concentração de potássio ao longo do perfil do solo. O terceiro e último capítulo atestou a viabilidade de se utilizar modelos consagrados no âmbito florestal, como o modelo de Schumacher-Hall na estimativa de nitrogênio, fósforo, potássio, cálcio e magnésio da biomassa aérea e raízes em plantio de eucalipto. Ao abordar aspectos da ciclagem biogeoquímica em povoamento florestal, este trabalho ressalta a importância do papel da eucaliptocultura na manutenção dos padrões de produção sustentável em um bioma tão devastado como o Cerrado.

Palavras-chave: ciclagem de nutrientes, Latossolo Vermelho (Oxisol), produção de serapilheira, decomposição foliar, potássio, modelos não lineares.

GENERAL ABSTRACT

The nutrient cycling in Eucalypt stand in Cerrado soil condition was the main theme of this thesis. The study was conduced at Água Limpa Farm which belongs to the University of Brasília, situated in the Distrito Federal. The stand has 3,29 ha of total area, establish in January 2010 (60 months). The planting of I224 clone, *Eucalyptus urophylla* S. T. Blake x *Eucalyptus grandis* Hill ex-Maiden was performed in 3 m x 2 m spacing. The soil of the stand was described as Red Latosol (Oxisol) with low fertility. By analyze of litterfall, litter layer, leaf decomposition, chemic a physics of soil and nutrient modeling it was possible to highlight the relevance of quantity and quality of organic residues in forest stand. In the first chapter were possible to observe higher litterfall and litter layer in Eucalypt stand, however with slow decomposition. In the second chapter was verified the effect of litter layer removal in the leaf decomposition and the potassium concentration in the soil profile. The third and last chapter demonstrated the viability of using forest models, such as the Schumacher-Hall for the estimation of nitrogen, phosphorus, potassium, calcium and magnesium by the aboveground biomass and roots in Eucalypt stand. Addressing aspects of biogeochemical cycling in forest stands, this work highlights the importance of keeping Eucalypt stand to in order to sustainnable production patterns in a devastated Brazilian biome, as the Cerrado.

Keywords: nutrient cycling, Red Latosol (Oxisol), litterfall, leaf decomposition, potassium, non-linear models.

1. INTRODUÇÃO GERAL

O eucalipto é uma espécie que pertence à família Myrtaceae, de crescimento rápido e com aproveitamento lenhoso bastante diversificado. No Brasil, essa espécie – que possui capacidade de se desenvolver em solo de baixa fertilidade – passou a figurar entre as principais categorias de produção agroindustrial na região central do país, em que o Cerrado é o bioma predominante. Com o predomínio da classe dos Latossolos, que são profundos, mecanizáveis, porém álicos e de baixa fertilidade, a eucaliptocultura na região se estabeleceu juntamente com desenvolvimento científico e tecnológico.

A partir do final da década de 60, empresas do setor florestal brasileiro e comunidade acadêmica intensificaram os estudos silviculturais do eucalipto por meio do melhoramento genético, zoneamento de plantios e resposta à adubação. Nos anos 80 o foco das pesquisas foi na propagação vegetativa por meio de plantios clonais. Na mesma década a empresa Aracruz passou a produzir por ano 50 m^3 por hectare (MOURA; GARCIA 2000) atestando, assim, o êxito dos investimentos realizados anteriormente. Neste mesmo período, porém, o segundo maior bioma brasileiro passou por transformações severas, com reduções consideráveis da sua vegetação original.

Diante do cenário de franco desenvolvimento agrícola da região central do país, o Cerrado se tornou uma das últimas fronteiras agrícolas do planeta (BORLAUG, 2002). As consequências desse processo de ocupação tornaram-se preocupantes, principalmente na região conhecida como “Arco do Desmatamento” (NOGUEIRA et al., 2007; NOGUEIRA et al., 2008), onde se concentra as maiores taxas de desmatamento, e que avançou em direção à região norte. Esse ritmo de devastação, aliado ao baixo nível tecnológico das propriedades rurais (SOUZA et al., 2013), é comprometedor, p. ex., em estudos que demostram o hiperdinamismo de florestas de transição entre o Cerrado e a Floresta Amazônica (MARIMON, et al., 2013).

Em função do estado em que se encontra um dos principais biomas brasileiros, a alternativa é focar em práticas realmente sustentáveis e que diminuam, ou até interrompam as pressões sobre as vegetações nativas. Assim, a implantação de povoamentos florestais configura como uma opção para diversificar a produção agroindustrial. A implantação de povoamento florestal possibilita menores perdas de carbono por hectare em comparação com culturas anuais, no caso a soja (BONINI et al., 2018). Monoculturas de eucalipto podem proporcionar aumentos de estoques de carbono em frações, como ácido húmico e fúlvico, em comparação com a vegetação natural do Cerrado e pastagem (PULROLNIK et al., 2009). A espécie também é eficaz ao manter níveis de crescimento satisfatórios, mesmo diante de déficits hídricos (ALMEIDA; SOAREAS, 2003).

A capacidade de produção de material aportado no solo via queda de serapilheira também é similar quando se compara plantios de eucalipto com florestas nativas (INKOTTE et al., 2015). Ao decompor, esse material passa a contribuir para entrada de carbono e nutrientes no solo. Em povoamentos de eucalipto, as folhas são responsáveis pela maior contribuição de material orgânico e posterior retorno de nutrientes para o solo (VIEIRA et al., 2014).

O retorno de nutrientes via decaimento de biomassa foliar, proporciona um balanço positivo, indispensável ao crescimento e ganho de biomassa. Esse favorecimento, aliado à uma correta adubação, resulta em melhorias nas qualidades anatômicas da madeira (SETTE JUNIOR et al., 2014). A implantação de sistemas agrossilviculturais, em que o eucalipto é o componente florestal, também é uma iniciativa que mostra resultados promissores, no intuito de diversificar a produção rural e aproveitar ao máximo a área disponível (CALIL et al., 2013; FIGUEIREDO et al., 2017).

Indagações a respeito dos impactos oriundos da eucaliptocultura são objetos de debates. Por isso, as pesquisas que focam no caráter sustentável de produção florestal, tornam-se ainda mais relevantes. É fato que toda monocultura, seja ela de cultivo anual ou perene, acarreta impactos. Entretanto, as monoculturas florestais não podem ser ignoradas nos debates a respeito da modernização ecológica (FARINACI et al., 2013).

O equilíbrio entre a preservação e os padrões de consumo depende de pesquisas científicas consistentes e que considerem os aspectos positivos e negativos, como é o caso da eucaliptocultura. Esta tese é uma contribuição científica, que buscou compreender melhor aspectos da relação solo-planta em povoamento de eucalipto não manejado sobre solo do Cerrado. Ao longo de três capítulos, foram abordados: o padrão de produção, acúmulo e decomposição de serapilheira; os impactos imediatos resultantes da remoção da camada de serapilheira; além de estimativas, por meio de modelagem, da quantidade de biomassa e nutrientes.

Os resultados obtidos neste documento contribuirão para o entendimento do papel da eucaliptocultura na proteção e conservação de solos do Cerrado. Assim, a decisão de implantar uma monocultura florestal, seja ela para fins econômicos ou puramente para proteção de solo, passa a ser sustentada por informações científicas consistentes.

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CAPÍTULO I*

Produção, acúmulo de serapilheira e decomposição foliar em povoamento de eucalipto sobre solo do Cerrado

Litterfall, litter layer and leaf decomposition in *Eucalyptus* stand on Cerrado soils

ABSTRACT

The success of Eucalypt cultivation in Brazil was the result of decades of research, improvement of cultivation technologies, along with favorable edaphoclimatic properties. Nowadays, Eucalypt plantations are the main source of wood in the country. However, there are persisting doubts about the impacts hydric, chemical and biological patters on the soil by this monoculture forest. For this reason, the understanding of the nutrient biogeochemical cycle linked to the litter dynamics contributes to elucidate the changes occurring in the physicochemical and biological properties of the soil. Thus, this work evaluated litterfall, litter layer and leaf decomposition in Eucalypt plantation 60 months-age in the Cerrado area, Federal District. 360 days after experiment initiation, the remaining mass of leaves corresponded to 68.72%, indicating a highly recalcitrant litter. It was concluded that there is an intense production and accumulation of plant material, which undergoes decomposition at a slow rate. This longer time of permanence of litter on the ground provides a favorable niche for edaphic fauna, protecting the superficial layer of the soil by reducing the impact of the kinetic energy of raindrops and allowing for improvement in water infiltration and, consequently, maintenance of the soil hydric capacity.

Keywords: remaining biomass, litter bags, *k* decomposition constant, dystrophic soil.

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RESUMO

O êxito da eucaliptocultura no Brasil foi resultado de décadas de pesquisa, aprimoramento de tecnologias de cultivo, aliado às propriedades edafoclimáticas favoráveis. Atualmente, os plantios dessa espécie são a principal fonte de madeira no país. Entretanto, dúvidas a respeito de impactos nos padrões hídricos, químicos e biológicos do solo, advindos dessa monocultura florestal ainda carecem de elucidações. Por esta razão, o entendimento do ciclo biogeoquímico de nutrientes ligado à dinâmica da serapilheira contribui para elucidar as modificações que ocorrem nas propriedades físico-químicas e biológicas do solo. Assim, este trabalho avaliou a produção, acúmulo e decomposição de serapilheira em plantio eucalipto aos 60 meses de idade em área de Cerrado no Distrito Federal. Aos 360 dias após o início do experimento, a porcentagem de massa remanescente correspondia a 68,72% indicando uma serapilheira altamente recalcitrante. Conclui-se que há uma intensa produção e acúmulo de material vegetal, porém com uma lenta decomposição. Esse maior tempo de residência da serapilheira proporciona um nicho favorável à fauna edáfica e proteção da camada superficial do solo, por meio da redução do impacto da energia cinética das gotas de chuva, possibilitando assim, uma melhora na infiltração de água e consequentemente manutenção da capacidade hídrica no solo.

Palavras-chave: biomassa remanescente, sacolas de decomposição, constante *k* de decomposição, solo distrófico.

1. INTRODUCTION

Litterfall is the main input form of carbon and nutrients to the soil; where they are important components of the biogeochemical cycle. In a Eucalypt stand, the material coming from the litter guarantees the return of nutrients to the soil (VIERA et al., 2014a), mainly due to the large amount of plant material deposited on the ground (GIÁCOMO et al., 2017). In addition, plant residues decompose to the formation of organic matter, which releases P, Fe, Mn, Zn and K as it is mineralized (VIERA et al., 2014b). In general, the balance of macronutrients in the soil-plant system is also positive in plantations conducted in dystrophic soils of the Brazilian Cerrado (GATTO et al., 2014).

In wetlands, production and decomposition of organic material occurs at a fast pace and consequently, there is a greater return of nutrients. In contrast, due to the edaphoclimatic conditions, production and decomposition of organic matter in the Cerrado tend to be slower, so much more in the case of Eucalypt plantations due to the high lignin present in the litterfall (COSTA et al., 2005). However, Eucalypt stands present good soil-water retention capacity (SUZUKI et al., 2014) and satisfactorily maintain soil physical properties (ASSIS et al., 2015).

Inquiries regarding impacts of plantations on large areas are often discussed (FARINACI et al., 2013). Such questions are completely valid and pertinent; nevertheless, it is for the scientific and the academic community to demonstrate the sustainability of Eucalypt culture in Brazil. Thus, this study aimed to evaluate litterfall, litter layer and leaf decomposition in Eucalypt stand in the Cerrado. The work also tested different periods of litter bags rescue in order to ascertain differences of the parameters obtained through the exponential regression.

2. MATERIAL AND METHODS

2.1. Study area and sample design

The work was conducted in the Água Limpa Farm, which belongs to the University of Brasília, situated in the Distrito Federal (15° 56'-15 59' S and 47° 55'-47 58' WGr.). The property occupies a total area of 4,340 ha, about 2,340 ha of which are intended for preservation, while 1,200 ha are for academic studies focused on wood production, livestock and agriculture.

The climate in the region is described after Köppen as AW, with maximum and minimum temperatures of 28.5 °C and 12.0 °C, respectively (ALVAREZ et al., 2014). During the collection period, from November 2015 to October 2016, average temperature was 21.0 °C; total precipitation was 1,115 mm, information made available by the Água Limpa Farm automatic climatological station (Figure 1). Soils within the study area are described as dystrophic Red Latosol (Oxisol).

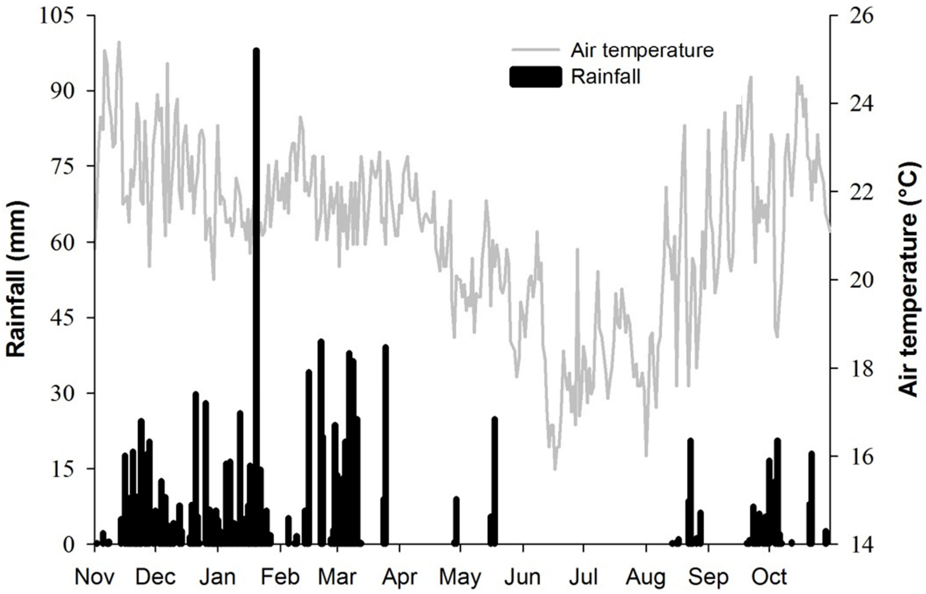

Figure 1. Rainfall (mm) and air temperature (ºC) from November 2015 to October 2016 at Fazenda Água Limpa, Universidade de Brasília, Distrito Federal.
Figura 1. Pluviosidade (mm) e temperatura do ar (ºC) de novembro de 2015 a outubro de 2016 na Fazenda Água Limpa, Universidade de Brasília, Distrito Federal.

The low base saturation (V < 50 %) and high aluminum saturation (m) make these soils dystrophic (SOUSA; LOBATO, 2004). The low Ca^{2+} + Mg^{2+} contents (Table 1) reflected the acidic nature of the soil. In this condition, the microbial activity is very limited, mainly bacterial (LAUBER et al., 2009), which results in low mineralization rates of organic matter (MIRANDA et al., 2007).

Table 1. Chemical attributes of a dystrophic Red Latosol under a Eucalypt stand at Água Limpa Farm, Distrito Federal*.
Tabela 1. Atributos químicos de um Latossolo Vermelho distrófico sob povoamento de eucalipto, na Fazenda Água Limpa, Distrito Federal*.

Depth (cm)	pH	P	K^+	$OC^{(1)}$	H+Al	Al^{3+}	$Ca^{2+} + Mg^{2+}$	$S^{(2)}$	$CEC_t^{(3)}$	$CEC_T^{(4)}$	$OM^{(5)}$	$BS^{(6)}$	$m^{(7)}$
	H_2O	mg dm^{-3}		mg g^{-1}	----------------------cmol$_c$ dm^{-3}---------------------						dag Kg^{-1}	-----%----	
0-20	4.9	2.6	12.9	26.0	8.9	0.70	0.39	0.4	1	9.3	4.5	4.6	60.5
20-40	5.1	1.4	14.7	20.5	20.5	0.26	0.36	0.4	1	7.6	3.5	4.7	42.3
40-60	5.5	1.7	16.2	4.10	5.1	0.04	0.43	0.5	1	5.6	0.7	8.6	6.8

(1)Organic carbon; (2)Sum of bases; (3)Cation exchange capacity (effective); (4)Cation exchange capacity (total); (5)Oganic Matter; (6)Base saturation; (7)Aluminum saturation index.
*Data collected: March 2016.

The stand selected for conducting the study comprises a total area of 3.29 ha and was established in January 2010 (60 months). The planting of I224 clone *Eucalyptus urophylla* S. T. Blake x *Eucalyptus grandis* Hill ex-Maiden was performed in a 3 m x 2 m spacing. Preparation of the soil was done by plowing down to 40 cm depth. Fertilization was practiced along the planting line by application of 100 g of super simple phosphate + 100 g of NPK (4-30-16); liming was not performed previously. A total of 40 plots, 10 m x 10 m plots were randomly marked for monthly monitoring of litterfall, litter layer and leaf decomposition along 12 months.

2.2. Litterfall

Forty litter traps (0.50 m x 0.50 m) were distributed along the centerline of each plot to quantify litterfall. The area sampled was within the recommended limit for litterfall samplings, which considers a minimum of eight litterfall traps per hectare (FINOTTI et al., 2003).

Monthly collections were performed between November 2015 and October 2016. Samples were divided into fractions to separate leaves, reproductive parts, branches and miscellaneous residues. Litterfall was quantified by means of constant dry weight after oven drying at 65 °C and weighing of the fractions on a precision scale.

2.3. Litter layer

The litter layer was evaluated through monthly collections from November 2015 to October 2016. In order to do the evaluation, a 0.50 m x 0.50 m metal template was randomly cast on the ground in each of the 40 plots; all the litter contained within the area covered by the metallic sheet was collected and oven dried at 65 °C to constant weight. Results are expressed in Mg ha^{-1}.

2.4. Leaf decomposition

Leaf decomposition rate was verified by means of the confinement of freshly fallen leaves into litter bags (20 cm x 20 cm) made of 2 mm nylon mesh. Each litter bag was filled with 21.00 g of leaf material and placed on the ground in each of the 40 plots for monthly redemption during the year of study.

Leaf decay was calculated as a function of mean biomass losses over time with the following equation: remaining mass (%) = (final mass/initial mass) × 100. The constant *k*, calculated for 30, 60, 120, 240 and 360 days after the start of the experiment (5 periods) and also monthly (12 periods), was obtained through the simple exponential equation proposed by Olson (1963); where $X_t = X_0.e^{-kt}$, (X_t= dry weight of material remaining after *t* days and X_0 = dry weight of material at t = 0). Half-life time was calculated by means of the equation $t^{1/2} = \ln(2)/k$ (OLSON, 1963).

2.5. Data analysis

Monthly data on litterfall, litter layer and leaf decomposition were compared by analysis of variance, followed by Tukey´s test to identify significant differences between monthly means. Residual normality and homogeneity of variances were verified by the Shapiro-Wilk and Levene tests, respectively. When these assumptions were not met, the Kruskal Wallis non-parametric test was used. Analyses were carried out using the PAST program 2.15 (HAMMER et al., 2001).

3. RESULTS

3.1. Litterfall

Total litterfall was 4.70 Mg ha^{-1} over the study period, during which, October was the month with the highest proction, although not statistically different from contributions in April, May or June. In contrast, December was the month with the lowest litterfall production, with an estimate similar to those found in January and August (Table 2). Except for November, the leaf fraction was the one that contributed most to total litterfall, with contributions above 50% from March (Table 2 and Figure 2).

The branches represented the second largest contribution to total litterfall production, followed by miscellaneous residues and last, reproductive parts. However, this pattern was not constant for all months of the year, e.g., in November/2015 and February/2016 branches contributed to litterfall more than leaves did (Table 2 and Figure 2). In July, reproductive parts contributed 9.2 % of litterfall production, higher percentage than that observed for branches and miscellaneous residues.

Table 2. Total litterfall (Mg ha^{-1}) and fractions (kg ha^{-1}) in Eucalypt stand at Água Limpa Farm, Distrito Federal.
Tabela 2. Produção total (Mg ha^{-1}) de serapilheira e frações (kg ha^{-1}) em povoamento de eucalipto, na Fazenda Água Limpa, Distrito Federal.

Months	Leaves	Reproductive parts	Branches	Miscellaneous	Total
November	43.7 (11.9%)	27.6 (7.5%)	176.1 (47.9%)	120.1 (32.7%)	0.3675c (100%)
December	54.2 (39.5%)	10.5 (7.7%)	38.8 (28.2%)	33.7 (24.5%)	0.1372d (100%)
January	76.4 (47.3%)	10.5 (6.5%)	42.5 (26.3%)	32.1 (19.9%)	0.1614d (100%)
February	143.1 (37.1%)	10.6 (2.8%)	151.0 (39.1%)	81.1 (21.0%)	0.3858bc (100%)
March	110.0 (78.8%)	5.0 (3.6%)	5.2 (3.7%)	19.4 (13.9%)	0.1396d (100%)
April	549.9 (97.9%)	6.2 (1.1%)	5.8 (1.0%)	16.4 (2.9%)	0.5619a (100%)
May	677.1 (94.9%)	5.9 (0.8%)	19.9 (2.8%)	10.9 (1.5%)	0.7138a (100%)
June	591.8 (93.7%)	11.9 (1.9%)	12.5 (2.0%)	15.4 (2.4%)	0.6316a (100%)
July	276.3 (82.7%)	30.7 (9.2%)	8.9 (2.7%)	18.1 (5.4%)	0.3339bc (100%)
August	157.9 (64.3%)	17.5 (7.1%)	35.2 (14.3%)	35.0 (14.2%)	0.2455bcd (100%)
September	299.4 (94.7%)	8.5 (2.7%)	8.4 (2.6%)	40.2 (12.7%)	0.3163bc (100%)
October	712.1 (91.6%)	8.4 (1.1%)	33.1 (4.3%)	23.8 (3.1%)	0.7774a (100%)
	-	-	-	-	H (11, 480)=347.91, p< 0.01
Total	**3.691,9 (77%)**	**153.2 (3%)**	**537.2 (11%)**	**446.1 (9%)**	**4.70 (100%)**

Means followed by the same lower case on the column do not differ.
Médias seguidas da mesma letra minúscula na coluna não diferem entre si.

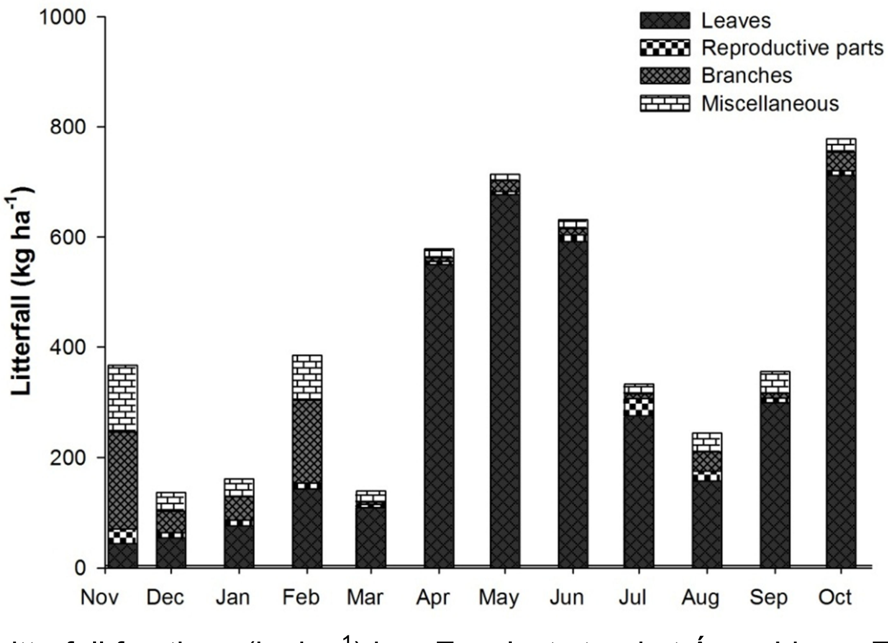

Figure 2. Litterfall fractions (kg ha^{-1}) in a Eucalypt stand at Água Limpa Farm, Distrito Federal.
Figura 2. Frações de serapilheira (kg ha^{-1}) em plantio de eucalipto, na Fazenda Água Limpa, Distrito Federal.

3.2. Litter layer

Average accumulation of litter layer over the study period was 14.88 Mg ha^{-1}. October and September showed the highest estimates (Table 3). Thus, as occurred with the litterfall, the end of the dry period and the beginning of the rainy season were the spans of higher contribution to the litter layer accumulation. The month with the lowest layer formation was June, although not differing significantly from December or January.

Table 3. Mean and standard deviation of litter layer (Mg ha^{-1}) in Eucalypt stands at Água Limpa Farm, Distrito Federal.
Tabela 3. Média e desvio padrão da camada de serapilheira (Mg ha^{-1}) em povoamento de eucalipto, na Fazenda Água Limpa, Distrito Federal.

Months	**Litter layer**
November	11.89 degi (±2.21)
December	13.65 chi (±3.64)
January	12.38 defgh (±2.42)
February	13.71 cg (±3.28)
March	16.31 bef (±3.39)
April	14.56 cf (±3.41)
May	14.17 ce (±3.07)
June	10.74 d (±2.10)
July	15.27 bc (±3.71)
August	17.83 ab (±5.29)
September	19.03 a (±4.34)
October	19.03 a (±4.35)
	$F_{(11, 468)}=23.81$, $p<0.01$
Mean	**14.88**

Means followed by the same lower case on the column do not differ by Tukey test at 5% probability.
Médias seguidas da mesma letra na coluna não diferem entre si por meio do teste de Tukey a 5% de probabilidade.

3.3. Leaf decomposition

When using all periods, monthly exponential regression litter bags retrieved a more pronounced curve showed by the exponential regression (Figure 3B), in agreement with the decay in only five periods (Figure 3A). This difference can also be attested in the values of constant *k*, which was 0.0009 for the five periods and 0.0008 for 12 periods (Table 4).

Table 4. Parameters obtained by means of exponential regression for leaf decomposition, using 5 or 12 periods in a Eucalypt stand at Água Limpa Farm, Distrito Federal.
Tabela 4. Parâmetros obtidos por meio da regressão exponencial para decomposição foliar, utilizando 5 e 12 períodos em povoamento de eucalipto, na Fazenda Água Limpa, Distrito Federal.

	5 periods	**12 periods**
Equation	$X_t=19.345*e^{-0.0009}$	$X_t=18.914*e^{-0.0008}$
k	0.0009	0.0008
$T^{1/2}$ (days)	770	866
Decomposed biomass (Mg ha^{-1})	1.70	1.70

Although it may seem a small difference, this distinction represents almost 100 days less when using the standard litter bags redemption time, which is five periods (Table 4). This causes overestimation of decay measurements, compared to what is observed when the *k* constant value is obtained through collections every month of the year. In one year, the total estimate of leaf decomposition was 1.70 Mg ha^{-1} (Table 4).

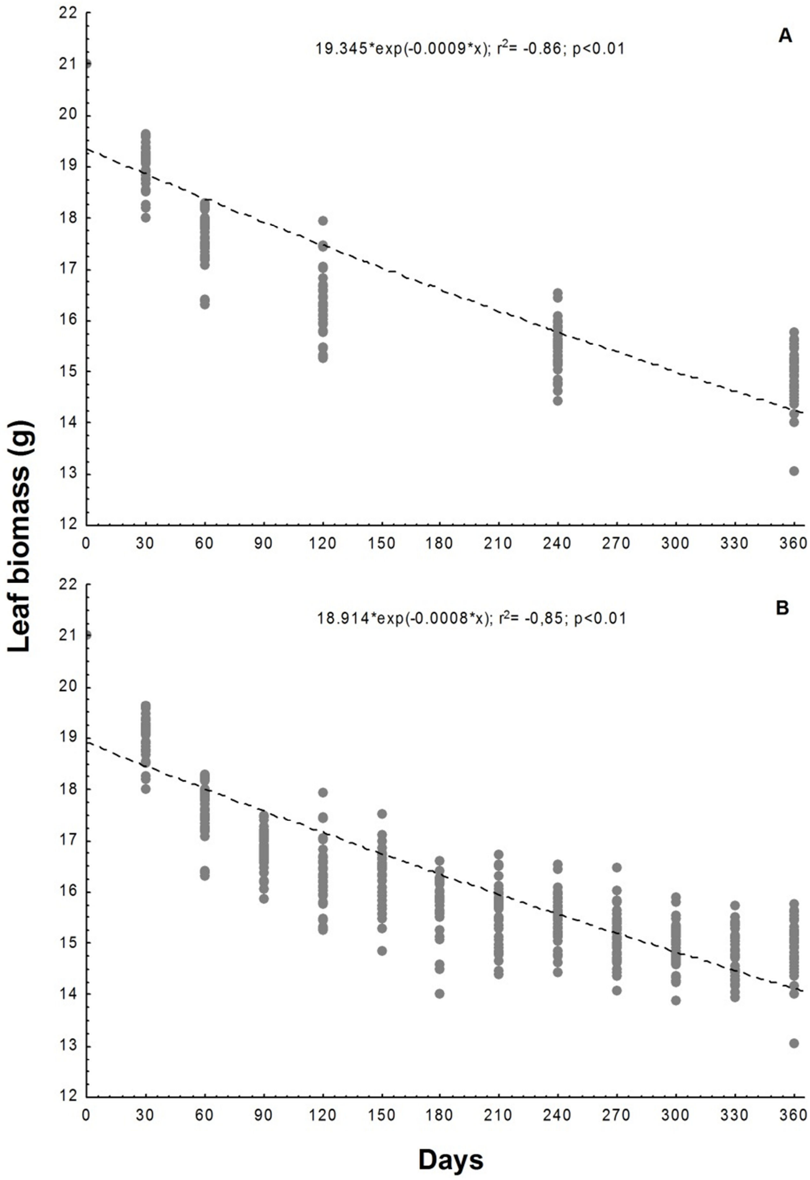

Figure 3. Exponential regression of leaf biomass decay (g) over 5 (A) and 12 (B) periods in a Eucalypt stand at Água Limpa Farm, Distrito Federal.
Figura 3. Regressão exponencial de decaimento de biomassa foliar (g) ao longo de 5 (A) e 12 (B) períodos em plantio de eucalipto, na Fazenda Água Limpa, Distrito Federal.

When comparing all the periods of decay of leaf biomass, it was possible to verify a difference in relation to the initial mass, in the zero time, only at 90 days after the beginning of experiment. At 360 days -last collection- the remaining material was 14.88 g, but this average did not differ from 210, 240 270, 300 and 330 days (Table 5). We verified that in one year, less than 50% of the leaf biomass contained in litter bags was decomposed.

Table 5. Average weight (g) and percentage of leaf biomass remaining during twelve periods in a Eucalypt stand, at Água Limpa Farm, Distrito Federal.
Tabela 5. Peso médio (g) e porcentagem de biomassa foliar remanescente ao longo de doze períodos em povoamento de eucalipto, na Fazenda Água Limpa, Distrito Federal.

Days after the beginning of experiment	Remaining leaf biomass
0	21.00a (100%)
30	19.01ab (87.8%)
60	17.61ac (81.3%)
90	16.85bc (77.8%)
120	16.31cd (75.3%)
150	16.27ce (75.2%)
180	15.78def (72.9%)
210	15.53deg (71.7%)
240	15.47fg (71.5%)
270	15.16fg (70.0%)
300	14.96g (69.1%)
330	14.84g (68.5%)
360	14.88g (68.7%)
	$H_{(12, 520)}$=430.70, $p < 0.01$

Means followed by the same lower case on the column do not differ.
Médias seguidas da mesma letra minúscula na coluna não diferem entre si.

4. DISCUSSION

4.1. Litterfall

Total litterfall values observed in this study agree well with those obtained in more recent stand in south and southeast regions of the country. In a stand of *E. dunnii* planted in spacing 2.0 x 3.5 m and at 16.5 months of age in Alegrete - RS, Corrêa et al. (2013) estimated 4.1 Mg ha^{-1}. Similarly, in the Sesmarias river basin, which includes the states of São Paulo and Rio de Janeiro, the production was 4.4 Mg ha^{-1} in a planting of hybrids *E. urophylla* and *E. grandis* with 3 x 2 m spacing and at 24 month of age (MELOS et al., 2010). Even in a crop-livestock-forest integrated system, in which corn was the crop component, Freitas et al. (2013) estimated the production of litterfall in 4.2 Mg ha^{-1} in an *E. grandis* x *E. urophylla* hybrid planting in the state of Minas Gerais, thus, demonstrating the viability of the hybrid to produce litterfall even in different planting sites and arrangements.

It should be emphasized that no acidity correction was made for the planting of the present study. Nevertheless, litterfall has not been affected over time. In addition to decreasing the action of exchangeable H^{+} and Al^{+} ions, liming raises Ca^{2+} and Mg^{2+} content in dystrophic soils, which are characteristically highly acidic. In so doing, liming provides elements which are highly demanded by Eucalypt. Another factor that may explain regular production of litterfall is biogeochemical cycling. Older plantings become more dependent on the litter deposited on the ground and its decomposition and release of nutrients to the soil (SCHUMACHER; VIEIRA, 2015).

The end of the drought, between September and October, was the period of greatest litterfall production. This factor may be related to the climatic conditions that predominate in the region in this period, dominated by low soil water content and, consequently, greater foliar abscission as it occurs in other species present in the biome (CIANCIARUSO et al. 2006; SILVA et al. 2007; GIÁCOMO et al. 2012). The lowest estimate of litterfall, which occurred in December/2015, is attributed to the beginning of the rainy season, in which the soil more effectively resumes its hydric capacity to provide the roots.

4.2. Litter layer

As observed for the estimation of litterfall contribution, the litter layer accumulated on the ground also presented higher average values in the month of October. This similarity may be related to inherent characteristics of dystrophic and alic soils. Under these conditions, microbial activity which may contribute up to half of the potential for soil nitrogen mineralization in Eucalypt plantations, tends to be lower (SOUSA et al., 2007; BARRETO et al., 2012).

In the soil condition before mentioned, litter layer estimates were higher than those reported by other studies conducted on hybrid *E*. *grandis* x *E*. *urophylla* plantations on Latosol (Oxisols) in the Cerrado (GATTO et al., 2014; LIMA et al., 2015a). The fact of being an unmanaged planting, aged 60 months and, can also be associated with this finding. In older stands, degradation of the contributed material tends to occur to a lesser extent, therefore indicating a slower decomposition (NOUVELLON et al., 2012).

4.3. Leaf decomposition

The percentage of remaining biomass in the litter bags still not decomposed was similar to that found in an *E*. *urophylla* plantation in the state of Bahia, in which Pinto et al. (2016) verified rates of 73.56 % at 180 days after the beginning of the experiment. In the state of São Paulo, Bachega et al. (2016) at 180 days after experiment initiation, it was 63.00 % of the leaf biomass remaining in the litter bags in an *E*. *grandis* planting. This pattern of recalcitrance seems to be characteristic of eucalypt leaves and may be mainly due to the high levels of lignin and polyphenols present.

Lignin and polyphenols are structural constituents of organic compounds that persist in the Eucalypt leaves. In the present study, leaf biomass decay was evidenced only after 90 days from experiment initiation. Pinto et al. (2016) reported that sugar content was the first to be decomposed over the first three months after leaves fell on the ground; however, lignin content tends to remain constant over a much longer period of time (COSTA et al., 2005). After the first quarter, most of the strongest structures rich in lignin, cellulose, waxes and tannins, such as ribs and petioles, still remain, reducing the rate of decomposition (CARVALHO et al., 2009; VIERA et al., 2014b; LIMA et al., 2015b).

Lignin, which is associated to the low palatability of organic plant residues for edaphic fauna (GAMA-RODRIGUES et al., 2003), contributes to the low value of the *k* rate of decomposition. In a planting of *E*. *grandis* x *E*. *urophylla*, in the state of Minas Gerais, Cunha Neto et al. (2013), obtained a *k* value of 0.0028 with a half-life of 247 days. Despite being a similar hybrid, inherent characteristics of the site may have influenced the low value of the constant in the present study.

Proposed by Olson (1963), rate *k*, obtained through exponential regression, is still one of the most didactic and safe methods to estimate the decomposition rate, usually of leaves, in forest environments. According to Scoriza et al. (2012) the confinement of leaves in litter bags provides a visual perception of material decay over time through the regression curve. However, by choosing to redeem in five periods, which is the usual practice, regression models may overestimate the *k* value. Indeed, in comparison to a model composed of 12 rescues, the difference in half-life was almost 100 days longer than when only five rescues are considered. This indicates that the assimilation capacity of precipitated organic matter in the soil, under Eucalypt stands, may be even lower.

5. CONCLUSION

The results obtained by sampling litterfall, litter layer and leaf decomposition in an Eucalypt stand showed high production of plant residues; however, the decomposition of this material in the soil was shown to be quite slow. This can be attributed mainly to the inherent of edaphoclimatic characteristics as well as to the characteristics of the plant residues. Although admittedly highly recalcitrant, litter from the Eucalypt stand can be an alternative for the preservation of the physical properties of the soil, particularly its hydric retention capacity. The use of a greater number of collection periods for determining the exponential regression of constant *k* is important in order not to overestimate the time of disappearance of the remaining biomass. Leaf decomposition was highly correlated with moisture in the soil subsurface layer.

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CAPÍTULO II*

Remoção da camada de serapilheira e implicações nos parâmetros de decomposição foliar e propriedades físico-químicas do solo em povoamento de eucalipto no Cerrado

Removal of litter layer and implications on leaf decomposition parameters and soil physicochemical properties in *Eucalyptus* stands in the Cerrado

ABSTRACT

Environmental impacts resulting from Eucalypt cultivation are widely debated and subordinated to justifications, often fallacious and without scientific support. It is a fact that annual and perennial monocultures cause impacts. However, when talking about conservation and increase of organic matter in the soil, perennial crops such as Eucalypt cannot be discarded. In this context, the objective of this work was to evaluate in a Eucalypt stand, the impact of the removal of litter layer on leaf decomposition and physicochemical properties in the Cerrado dystrophic soil. Removal of litter layer occurred every two months. In forty plots, twenty non-removed and twenty removed litter layer were obtained data of litterfall, leaf decomposition and physical and chemical properties of the soil. The removal of the layer increased the estimated time of leaf decomposition and caused changes in potassium concentration and soil moisture. Through the results it was possible to complete the environmental relevance of organic waste, even though from a perennial monoculture.

Keywords: dystrophic soil, litter bags, *k* decomposition constant, soil moisture, soil macronutrients

**Este capítulo foi redigido, em língua inglesa, no formato de artigo, de acordo com as normas do periódico Cerne: Qualis CAPES: B1; JCR (2017): 0,50.*

RESUMO

Impactos ambientais decorrentes da eucaliptocultura são amplamente debatidos e subordinados a justificativas, muitas vezes, falaciosas e sem respaldo científico. É fato que monoculturas anuais e perenes causam impactos. Porém, quando se fala em conservação e incremento de matéria orgânica no solo, culturas perenes, como o eucalipto, não podem ser descartadas. Neste contexto, o objetivo deste trabalho foi avaliar, em um povoamento de eucalipto, o impacto da remoção da camada de serapilheira na decomposição foliar e nas propriedades físico-químicas de um solo distrófico do Cerrado. A remoção da camada de serapilheira ocorreu a cada dois meses. Em quarenta parcelas, vinte com a não remoção e vinte com remoção da serapilheira foram obtidos dados de produção, decomposição foliar e propriedades físicas e químicas do solo. A remoção da camada aumentou o tempo estimado de decomposição das folhas e causou alterações na concentração de potássio e umidade do solo.

Palavras-chave: solo distrófico, sacolas de decomposição, constante *k* de decomposição, umidade do solo, macronutrientes do solo

1. INTRODUCTION

Historical changes in land use were cost expensive for the Brazilian savanna biome. Currently the Cerrado, which was a mosaic of savannas and forest phytophysiognomies (RIBEIRO; WALTER, 2008), is a fragmented biome composed of underutilized areas that exposes the soil to irreversible degradation processes (HUNKE et al., 2015a; ANACHE et al., 2018). Due to the history of severe changes, the recovery of these areas becomes essential. However, how to do this in an acid soil with naturally low fertility?

Since the beginning of the 20th century, Eucalypt plantations, which primarily met the demand of Companhia Paulista de Estrada de Ferro, are the main source of timber in the country. Nowadays occupying an area of 5.67 million hectares (IBÁ, 2018), this wood tree has been genetically improved allowing its establishment in various site conditions.

However, due to the inherent environmental impacts of a monoculture, Eucalypt became the subject of discussion and controversy (FARINACI et al., 2013). Nevertheless, scientific studies attest to the ability of stands to provide benefits to soil e.g. nutrient mineralization and increased water retention capacity (GATTO et al., 2014; SUZUKI et al., 2014; ASSIS et al., 2015).

These positive factors are linked to the litterfall and its respectively decomposition. In this sense, the manipulation, i.e., the removal or addition of plant residues attests to the effect of this organic component on the soil nutrient availability and soil respiration of the Cerrado (VILLALOBOS-VEGA et al., 2011). The handling of residues in Eucalypt stands also positively affects the productivity of commercial plantations (MENDHAM et al., 2014).

In order to attest the litterfall ability to promote soil benefits in Eucalypt stand, the objective of this work was to show the impacts of litter layer removal on litterfall, leaf decomposition and physicochemical properties in a Eucalypt stand growing in Cerrado dystrophic soil condition. It was hypothesized that removal of litter layer would decrease the leaf decomposition rate and alter the physical and chemical soil characteristics.

2. MATERIAL AND METHODS

2.1. Study area

The Eucalypt stand was located at Água Limpa Farm (Figure 1), which belongs to the University of Brasília, situated at the Distrito Federal (15° 56'-15 59' S and 47° 55'-47 58' WGr.). The farm has 4,340 ha of total area, about 2,340 ha of which were intended for preservation, while 1,200 ha were for academic studies focused on wood production, livestock and agriculture.

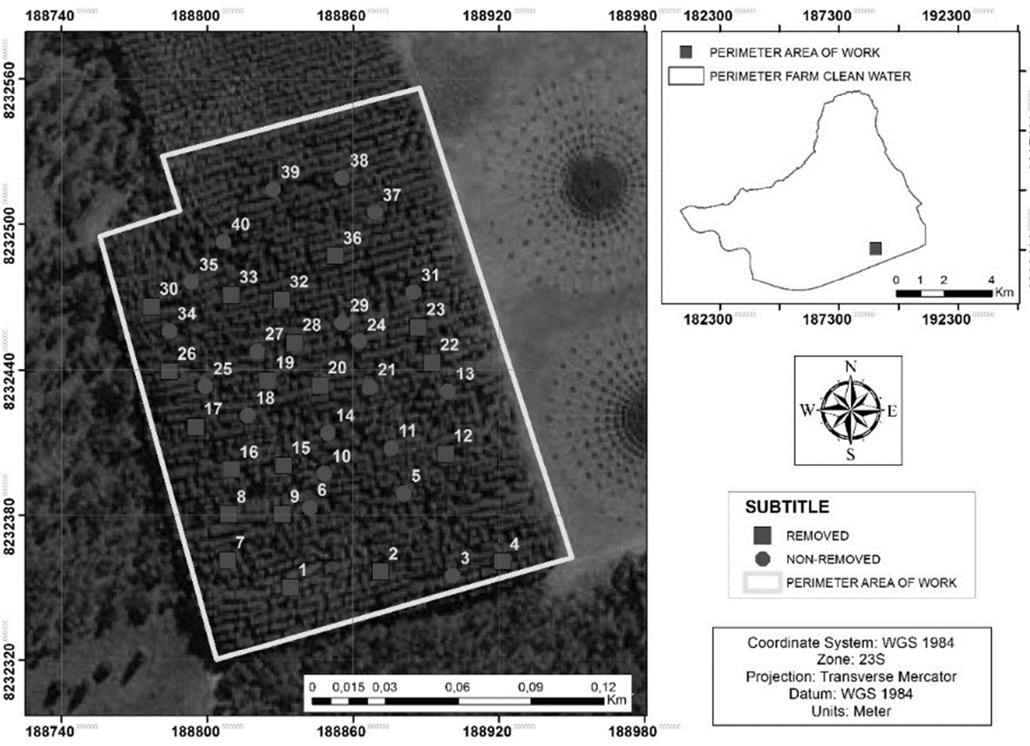

Figure 1. Eucalypt stand and experimental plots at Água Limpa Farm, Distrito Federal.

The weather in the region is described by Köppen as AW, with maximum and minimum temperatures of 28.5 °C and 12.0 °C, respectively. During the collection period, from November 2016 to October 2017, average temperature was 21.03 °C; total precipitation 907.00 mm, both parameters was acquired by the Água Limpa Farm automatic climatological station (Figure 2). Soils in the stand area are described as dystrophic Red Latosol (Oxisol).

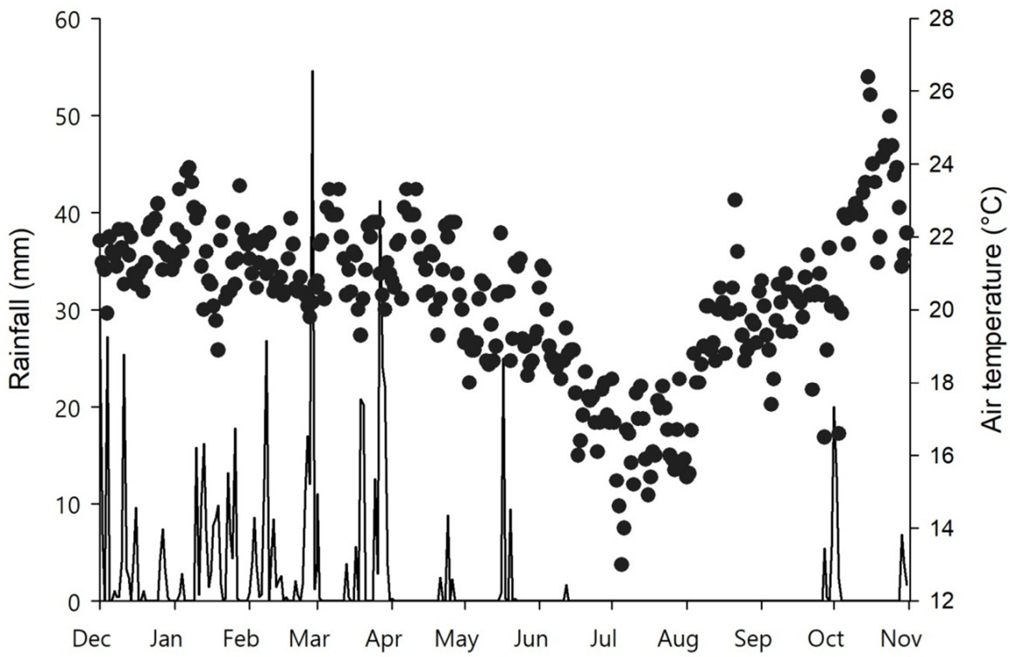

Figure 2. Rainfall (mm) and air temperature (ºC) from December 2016 to November 2017 at Fazenda Água Limpa, Universidade de Brasília, Distrito Federal.

The Eucalypt stand was established in January 2010 (72 months), with a total area of 3.29 hectares. The planting of I224 clone *Eucalyptus urophylla* S. T. Blake x *Eucalyptus grandis* Hill ex-Maiden was performed in 3 m x 2 m spacing. Soil preparation was done by plowing down to 40 cm depth. Fertilization was done along the planting line by application of 100 g of super simple phosphate + 100 g of NPK (4-30-16); liming was not performed previously. The 10 m x 10 m plots were randomly being twenty plots of non-removed litter layer and another twenty of removed litter layer (Figure 1). The litter layer was removed every two months during the experiment.

The soil sampling for determination of physical parameters was done in January, March, May, July, September and November in 2017. Chemical soil samples were collected in was in August 2017during the dry period.

2.2. Litterfall

Forty litterfall traps, with 0.25 m^2 area were distributed along the centerline of each plot to quantify litterfall. The area sampled was within the recommended limit for litterfall samplings, which considers a minimum of eight litterfall traps per hectare (FINOTTI et al., 2003).

From December 2016 to November 2017 monthly collections were performed. Samples were separated into fractions to separate leaves, reproductive parts, branches and miscellaneous residues. Litterfall was quantified by means of constant dry weight after oven drying at 65 °C and weighing of the fractions on a precision scale.

2.3. Leaf decomposition and chemical attributes

The leaves decomposition rate was verified by the confinement of freshly fallen leaves into litter bags (20 x 20 cm) made of 2 mm nylon mesh. Each litter bag was filled with 20.00 g of leaf material and placed on the ground in each of the 40 plots for monthly collection during the year of study.

Leaf decay was calculated as a function of mean biomass losses over time with the following equation: remaining mass (%) = (final mass/initial mass) × 100. The constant *k*, calculated monthly (12 periods), was obtained through the simple exponential equation proposed by Olson (1963):$X_t = X_0 . e^{-kt}$, where X_t = dry weight of material remaining after t days and X_0 = dry weight of material at t = 0). Half-life time was calculated by means of the equation $t^{\frac{1}{2}} = \ln(2)/k$ (OLSON, 1963).

The P, K, Ca and Mg concentration in the leaves were determinate by nitro-perchloric digestion and analyze at Inductive Coupling Plasma. Sulfuric digestion and distillation were used for N concentration by the Kjeldahl method.

2.4. Soil physics and fertility

The chemical properties of soil samples are important measurements to evaluate its acidity and fertility intrinsic characteristics. In twenty non-litter removed and twenty litter-removed plots, six combined soil cores samples at a 0-20, 20-40 and 40-60 cm of depth were collected and analyzed. The soil was collected in August 2017 during the dry season.

The acidy was determined by the concentration of pH by distilled water method; exchangeable aluminum (Al^{3+}), potential acidity (H + Al) by titration. Phosphorus (P) and potassium (K) by Mehlich-1 extractor, P was determined using molecular absorption spectrophotometer and K by photometer of flame; calcium (Ca^{2+}), magnesium (Mg^{2+}) were measured by atomic absorption spectrophotometer; organic matter (OM) by extraction and titration. By the results it was possible to calculate the total cation exchange capacity (CECT), effective cation exchange capacity (CECt), sum of bases (SB), base saturation (V) and saturation by aluminum (m).

The density and the volumetric humidity were evaluated by the volumetric ring method, according to Claessen (1997) at 0-20, 20-40 and 40-60 cm depth. These physical soil properties were evaluated in January, March, May, July, September and November in 2017.

2.5. Data analysis

The litterfall, leaf decomposition and physicochemical soil properties were compared by analysis of variance. The comparison between non-removed and removed litter layer plots was made by independent t-test followed.

Tukey´s test was made *a posteriori* to identify significant differences between means. Normality and homogeneity of variances were verified by the Shapiro-Wilk and Levene tests, respectively. When these assumptions were not met, the Kruskal Wallis non-parametric test was used. Analyses were carried out using the PAST program 2.15 (HAMMER et al., 2001).

3. RESULTS

3.1. Litterfall

No differences were found to litterfall comparing non-litter removed and litter removed plots (Table 1). During the month of October, for both treatments, higher litterfall was observed; however, there was no distinction from May, June, July, August and September in both treatments. On the order hand, December was the one with the lowest production in both plots.

Table 1. Total litterfall (Mg ha^{-1}) during twelve months in Eucalypt stand with non-litter removed and litter removed at Água Limpa Farm, Distrito Federal.

Months	Non-removed	Removed
December	0.12Afg	0.12Ai
January	0.43Abcd	0.46Adegj
February	0.17Adefi	0.28Afghi
March	0.34Acghi	0.39Adeh
April	0.39Abce	0.46Abcdef
May	0.60Aac	0.80Aae
June	1.08Aab	0.83Aad
July	1.23Aa	1.07Aab
August	1.02Aa	1.06Aac
September	0.36Abcf	0.34Adei
October	1.31Aa	1.48Aa
November	0.20Adefh	0.17Ahij
	H (11, 240)=172.86, p < 0.01	H (11, 240)=167.79, p < 0.01
Total	**7.33a**	**7.50a**

Means followed by the same upper case on the line and lower case on the column did not differ according to Tukey test at 5% of probability.

The contribution for each litterfall fraction to litter layer has shown that leaves were the main attribute contributing to the litter layer formation, except in November, when miscellaneous had contributed more (Figure 3). Non-litter removed and litter removed plots have showed similar litterfall pattern.

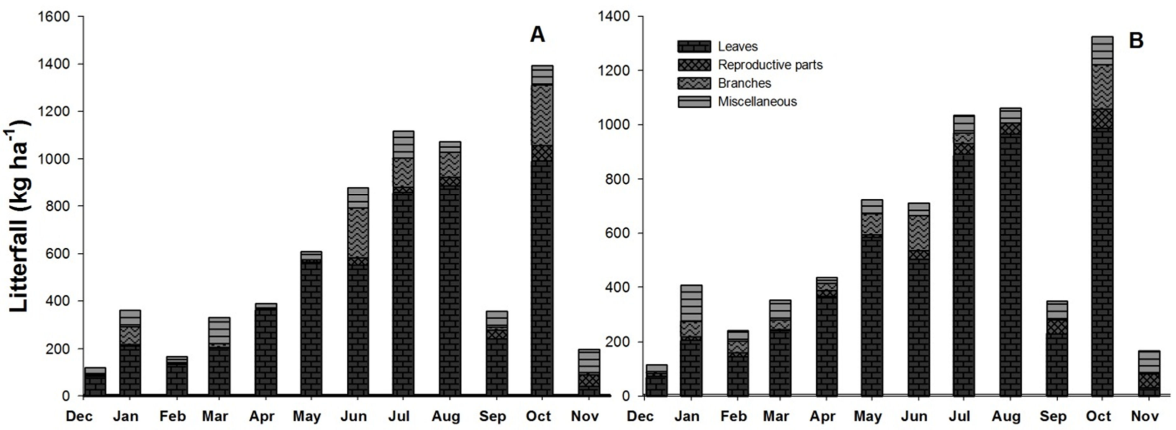

Figure 3. Litterfall fractions (kg ha^{-1}) during twelve months in Eucalypt stand with non-litter removed (A) litter removed (B) litter layer at Água Limpa Farm, Distrito Federal.

3.2. Leaf decomposition

The leaf biomass decay showed a distinct patter comparing non-removed and removed litter layer plots. In general, the material degradation was more constant in non-litter removed than litter removed plots; this pattern could be better illustrated by exponential regression (Figure 4).

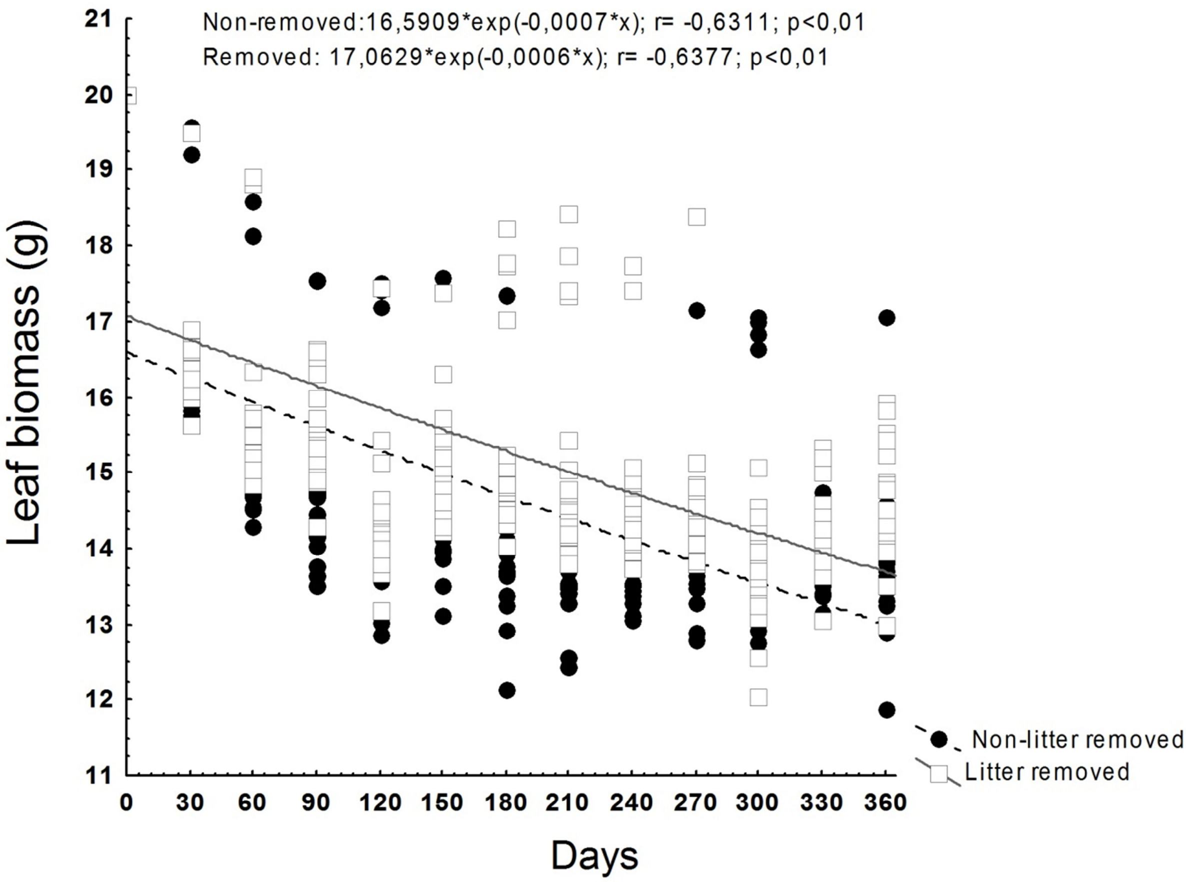

Figure 4. Exponential regression of leaf biomass decay (g) during one year in non-litter removed and in a Eucalypt stand at Água Limpa Farm, Distrito Federal.

The constant *k*, obtained by the exponential regression also reinforced the distinction between litter removed plots treatments. For the non-litter removed plots the *k* constant was 0.0007 while in the litter removed, was 0.0006. Although it may seem approximate values, this difference represented the delay of almost one-half of a year in relation to the half-life ($T^{1/2}$), which represents 990, and 1,155 days respectively in non-litter removed and litter removed plots.

The comparison between the days after the beginning of the experiment presented distinction. In nine periods the mean of leaf biomass was greater in non-litter removed than litter removed plots (Table 2).

Table 2. Remaining leaf biomass weight (g) and percentage (%) during one year in non-litter removed and litter removed plots in a Eucalypt stand, at Água Limpa Farm, Distrito Federal.

Days after the beginning of the experiment	**Remaining leaf biomass (g)**	
	Non-litter removed	**Litter removed**
0	20.00 (100%)a	20.00(100%)a
30	16.40 (82%)a	16.55 (83%)a
60	15.28 (76%)a	15.71 (78%)a
90	14.58 (73%)a	15.49 (77%)b
120	14.61 (73%)a	14.56 (73%)a
150	14.34 (72%)a	15.16 (76%)b
180	14.10 (70%)a	15.35 (76%)b
210	13.61 (68%)a	15.12(75%)b
240	13.73 (68%)a	14.69 (73%)b
270	13.87 (69%)a	14.64 (73%)b
300	13.77 (68%)a	14.21 (71%)b
330	13.76 (68%)a	14.21 (71%)b
360	13.87 (69%)a	14.59 (73%)b

Means followed by the same lowercase letter on the line do not differ, according to Tukey test at 5% of probability.

Nitrogen content was also higher at 360 days in both treatments comparing to the zero time. In no-removed plots, in addition to nitrogen, calcium also had higher mean concentrations compared to time zero (Table 3). The levels of K, Mg and C decreased in both treatments, but there was no statistical difference for the concentration of Ca in removed plots (Table 3). At the end of one year, the concentrations of K, Ca, Mg and C were lower in the leaves deposited on the soil of the removed plots comparing both treatments (Table 3).

Table 3. Chemical characteristics of leaves at day 0 and day 360 days in non-litter removed and litter removed plots in Eucalypt stand, at Água Limpa Farm, Distrito Federal.

	N	P	K	Ca	Mg	C
Non-litter removed Plots	---------------------------- dag kg^{-1} ------------------------					
Day – 0	0.64a	0.03a	0.22a	0.61a	0.34a	56.45a
Day – 360 – non-litter removed	0.82b	0.03a	0.07b	0.70b	0.25b	55.69b
Litter removed Plots	---------------------------- dag kg^{-1} ------------------------					
Day – 0	0.64a	0.03a	0.22a	0.61a	0.34a	56.45a
Day – 360 – litter removed	0.79b	0.03a	0.06b	0.63a	0.20b	53.68b
	-------------------------- dag kg^{-1} ------------------------					
Day – 360 – non-litter removed plots	0.82a	0.03a	0.07a	0.70a	0.25a	55.69a
Day – 360 – litter removed plots	0.79a	0.03a	0.06b	0.63b	0.20b	53.66b

Means followed by the same lowercase letter on the column do not differ, according to Tukey test at 5% of probability.

3.3. Fertility and physics of soil

Chemical soil analyzes (Table 4) showed low base saturation (V<50%) and high aluminum saturation (m) classifying this soil as dystrophic (SOUSA; LOBATO, 2004), the most common soil type in Brazilian Cerrado. The texture was considered very clayey and according Sousa e Lobato (2004) the levels of P, K, Ca^{2+}, Mg^{2+}, CEC_t, CEC_T, SB and OM at 0-20 cm of depth are considered low.

Potassium and base saturation were different comparing different treatments. The concentration of K was different in the three depths in non-litter removed plots, however, in litter removed plots 20-40 and 40-60 cm did not show statistic difference (Table 4). Base saturation did not differ in non-litter removed plots (Table 4) however, in litter removed the mean at 0-20 cm, it showed difference compared to the two deeper layers (Table 4). Others chemical attributes (e.g. pH, OM, P, Mg^{2+}, Al^{3+}, H+Al, CEC_t, CEC_T, SB and m) were similar in both treatments with larger mean values in depth of 0-20 cm (Table 4).

Table 4. Chemical attributes of a dystrophic Red Latosol (Oxisol) under a Eucalypt stand in non-litter removed and litter removed plots at Água Limpa Farm, Distrito Federal.

Depth (cm)	pH	OM	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	CEC_t	CEC_T	SB	V	m
Non-litter removed	H_2O	dag kg^{-1}	----mg dm^{-3}----		----------cmol$_c$ dm^{-3}----------							--------%--------	
0-20	4.9b	4.5a	0.35b	13.5a	0.03a	0.12b	0.41b	7.4a	0.59b	7.55a	0.18b	2.35a	69.73b
20-40	5.2a	3.1b	0.15a	4.2b	0.02a	0.06a	0.01a	4.4b	0.10a	4.53b	0.10a	2.06a	0.01a
40-60	5.1a	2.6c	0.01a	1.8c	0.02a	0.05a	0.01a	3.7c	0.07a	3.74c	0.07a	1.97a	0.01a
Litter removed	H_2O	dag kg^{-1}	----mg dm^{-3}----		----------cmol$_c$ dm^{-3}----------							--------%-------	
0-20	4.9b	4.3a	0.68b	14.0b	0.03a	0.11b	0.44b	7.3a	0.62b	7.43a	0.18b	2.37b	70.62b
20-40	5.1a	2.9b	0.13a	4.0a	0.01a	0.04a	0.01a	4.4b	0.05a	4.44b	0.05a	1.20a	0.01a
40-60	5.0a	2.4c	0.20a	2.3a	0.01a	0.03a	0.01a	3.7c	0.04a	3.69c	0.04a	1.18a	0.01a

Means followed by the same lowercase letter on the column do not differ, according to Tukey test at 5% of probability.

The soil moisture on the depth interval 40-60 cm was higher in the litter removed plots in January. Also during the rainy season, in March, there was a difference between depth interval 0-20 and 40-60 cm, only on non-litter removed (Table 5).

In May, which was preceded by 12 days without raining, the non-litter removed plots presented higher moisture at the 0-20 cm soil depth interval (Table 5). In September, soil moisture was lower in the 0-20 cm compared to 20-40 and 40-60 intervals only in the litter removed plots (Table 5).

The density in the litter removed plots was at 40-60 cm compared to 0-20 cm depth interval in September; this month was preceded by 91 days without raining (Figure 2). In non-litter removed plots, the density of the 0-20 cm interval was the lowest in November, after occurrence of precipitation (Table 5). The porosity parameter was similar to the density, with the exception of January, when the average was higher in non-litter removed (Table 5).

Table 5. Physical soil parameters in non-litter removed and litter removed plots during 2017 in a Eucalypt stand, at Água Limpa Farm, Distrito Federal.

		Moisture ($m^3 m^{-3}$)		Density ($kg dm^{-3}$)		Total porosity ($m^3 m^{-3}$)	
		Non-litter removed	Litter removed	Non-litter removed	Litter removed	Non-litter removed	Litter removed
	Depth (cm)						
January	0-20	29.52aA	30.90aA	0.94aA	0.95aA	64.17aA	63.94aA
	20-40	26.88aA	28.45aA	0.94aA	0.96aA	64.52aA	63.46aA
	40-60	24.46aA	27.59bA	0.96aA	0.95aA	66.47aA	63.84bA
March	0-20	27.34aB	28.05aA	0.91aA	0.89aA	65.62aA	66.35aA
	20-40	30.28aAB	30.36aA	0.94aA	0.99aA	66.88aA	62.37aA
	40-60	31.58aA	30.80aA	0.96aA	0.92aA	63.43aA	64.97aA
May	0-20	25.21aA	22.59bA	0.94aA	0.89aA	64.25aA	67.50aA
	20-40	24.49aA	23.66aA	0.93aA	0.90aA	64.77aA	65.96aA
	40-60	24.28aA	23.42aA	0.91aA	0.88aA	65.33aA	66.66aA
July	0-20	25.21aA	22.49aA	0.88aA	0.90aA	66.61aA	65.94aA
	20-40	22.59aA	22.75aA	0.87aA	0.89aA	66.88aA	66.22aA
	40-60	23.61aA	22.90aA	0.90aA	0.89aA	65.68aA	66.41aA
September	0-20	23.19aA	21.02aB	0.97aA	0.89aB	63.05aA	66.30aB
	20-40	23.82aA	23.98aA	0.94aA	0.95aAB	64.46aA	63.89aAB
	40-60	23.98aA	25.62aA	0.93aA	0.99aA	64.69aA	62.38aA
November	0-20	31.95aA	32.17aA	0.84aA	0.86aA	68.16aA	67.42aA
	20-40	36.89aA	36.87aA	1.00aB	0.97aA	62.16aB	63.38aA
	40-60	34.26aA	37.01aA	0.91aAB	0.94aA	65.63aAB	64.23aA

Means followed by the same lowercase letter in the row and uppercase in column do not differ.

4. DISCUSSION

4.1. Litterfall

During the study the litterfall was higher than other stands in Brazilian biomes (e.g. in Pampa biome) (CORRÊA et al., 2013) and Eucalypt stand previous occupied by Altantic forest in Rio de Janeiro (MELOS et al., 2010). Probably the higher deposition of litter was influenced mainly by the seasonality of the Cerrado, where trees may lose part of the leaves due to the low water availability during the driest period.

The total litter observed in this experiment was higher comparing with a stand located in similar edafoclimatic conditions, planting spacing and age (VIEIRA et al., 2009),. This distinction could be attributed to the different microclimatic conditions, fertilization of planting and quality of the planted seedlings.

This pattern of high litterfall is related to the age of the stand (REIS; BARROS, 1990; SCHUMACHER et al., 2013), and the canopy closure with reduction of the luminosity that favors the natural pruning. These conditions reflect high litter layer (e.g. in stands established in low fertility in the Cerrado biome) (RIBEIRO et al., 2017; VALADÃO et al., 2019).

The litter layer removal did not affect litterfall in one year. Although older stand become are more dependent to the organic material deposited in the soil by litterfall (SCHUMACHER; VIEIRA, 2015), the indistinct pattern between non-litter removed and litter removed plots may be related to the short time of litter layer removal. In Cerrado *sensu stricto* Villalobos-Vega et al. (2011) reported changes in the litterfall pattern in plots submitted to litter layer manipulation un the second year.

4.2. Leaf decomposition

The pattern of leaf decomposition was changed as a result of the litter layer removal, just in one year. Removal of litter layer results in substantial changes in Cerrado soils, as asserted by Villalobos-Vega et al. (2011); it implies changes in maximum soil temperature, water content and soil respiration. These variations may affect the heterotrophic and autotrophic respirations and the litter decomposition which are responsible for 41% of the total CO_2 efflux from the soil (VERSINI et al., 2013).

The leaves from Eucalypt are rich in tannin and polyphenols (SANTOS et al., 2018). In general, even after three months in which the leaves are deposited in the soil, structural constituents, for example, lignin still remain, reducing the decomposition rate (CARVALHO et al., 2009; VIERA et al., 2014; LIMA et al., 2015).

The removal of organic residues in Eucalypt stand results in a decrease in diametric growth in the first and second rotation cycles (ROCHA et al., 2016). Even in one year the decomposition pattern was changed in litter removed plots. Although the Eucalypt stand has good wood productivity in soils with low fertility and acid, the nutritional content of plant residues tend to decrease when the stand get older (ALI et al., 2017). When removing the litter, the N and P concentrations are altered and can influence the capacity of the microbial biomass to assimilate the litterfall (ROCHA et al., 2016).

The litter layer removal and the age of the stand can alter the nutrient concentration pattern in the soil. After 4.5 years there is a greater magnitude of the biogeochemical cycling, mainly in the process of foliar senescence in Eucalypt monoculture (ALI et al., 2017) and greater litterfall in the soil (SCHUMACHER; VIEIRA, 2015).

The sequence of decreasing concentration of nutrients was N> Ca> Mg> K> P in newly fallen leaves (day 0), non-litter removed and litter removed plots (day 360). There was an increment of N and Ca concentration from the beginning to the end of the experiment. During the initial period of decomposition there is a carbon metabolization and N immobilization by the microorganism (RAWAT; SINGH, 1995). The amount of lignin increases during the first half of the year in Eucalypt leaves (COSTA et al., 2005); the relationship between N concentration and changes in absolute amount of carbon indicate that the higher initial amount of lignin the result in greater amount of nitrogen immobilized per unit of carbon respired (MELILLO et al. 1982).

In leaves, calcium has low mobility and great amount of Ca is located in the cell wall (LIMA et al., 2018). During the decomposition process of the Eucalypt leaves the release of Ca is low, after 36 months 80 % of this macronutrient still present in the leaves (VEIRA et al., 2014).

Potassium was showed greatest decrease between the beginning and the end of the experiment in non-litter removed and litter removed plots. This decrease, was also verified by Carvalho et al. (2017) in Eucalypt stands, and it is justified by the fact that K participates in the structure of the plant tissue, besides being easily leached by water that percolates through the soil profile (DUTTA; AGRAWAL, 2001; VILELA et al., 2004). Although, comparing Eucalypt stand to native and regeneration forest the K leach is more slowly (CARVALHO et al., 2017)

4.3. Fertility and physics of soil

Even with low natural fertility, the Oxisol have high agricultural potential; this viability was essential for the establishment of Eucalypt stand on Cerrado. In the end 70's and early 80's NOVAIS et al. (1979) and NEVES et al. (1982) already reported, under nursery and field conditions, the tolerance of Eucalypt to acid soils, and considering liming to raise levels of calcium and magnesium (BARROS et al., 2014).

The distinctions observed in chemical attributes are resulted from pedogenetic processes. Cantarutti et al. (2007) argue that cultural practices, such as localized fertilization, and the root system of cultivated plants accentuate this variability among the different layers of the soil. The distinction of the mean concentrations of K and consequently V may be a reflection of the removal of the litter layer, non-litter removed and litter removed plots, did not differ between the depth intervals of 20-40 and 40-60 cm (Table 4).

The potassium has great soil mobility (ERNANI et al., 2007), the removal of the litter layer have facilitated by the water penetration, the percolation of the macronutrient to lower layers of soil. This distinction for potassium was not observed in sandy soil that received an increase of organic material coming from the Eucalypt harvest in the Congo (VERSINI et al., 2014). However, the amount of clay in Cerrado Latosol (Oxisol) can reduce the percolation of mobility elements in the soil.

The change of land use in Cerrado Latosol (Oxisol) causes a decrease in potassium concentration (e.g. sugarcane crop) (HUNKE et al., 2015). However, in Crop-Livestock-Forest Integration system (CLFI) when Eucalypt is the forest component, there is no difference between original Cerrado for K concentration (RAMOS et al., 2018).

However the of Eucalypt harvest residue was not able to increase the concentration of potassium in an 8-year cut cycle Eucalypt stand, established in a Cerrado Oxisol (ROCHA et al., 2016). The increment of organic material was not able to result in significant changes in the fertility of the dystrophic soil, thus a increment by mineral fertilization is recommended.

Contrasting with the low levels of macronutrients according to the chemical analysis, the amount of organic matter was considered satisfactory (SOUSA; LOBATO 2004) in both treatments (Table 4). Tacca et al. (2017) assert that Eucalypt monoculture influences the decrease of the soil fauna diversity (e.g. arthropod fauna) compared to native forest.

Moisture, density and total porosity, presented differences between non-litter removed and litter removed plots. In the case of moisture, Villalobos-Vega et al., (2011) also found distinctions in water content at the height of the dry period (e.g. September) at the height of the dry season, in plots that litter layer was removed in Cerrado *sensu stricto* natural vegetation also in the Federal District. The maintenance or the transport of the plant residue could protect exposed areas, ensuring ecosystem functions

The improvement in the soil physical quality also verified in Crop-Livestock-Forest Integration System (CLFIS) when the forest component was Eucalypt. Assis et al., (2015) verified improvements in density and porosity parameters when comparing CLFIS with degraded pasture in Oxisol. The benefit of forest residues maintenance is also verified at the time of harvest, with reduction in soil compaction levels (LOPES et al., 2015). Versini et al., (2013), reinforce the idea that the management of organic residues of forest stands plays a crucial role in ensuring the sustainability of tropical soils with low natural fertility.

5. CONCLUSION

The removal of litter changed the pattern of leaf decomposition, fertility and soil physics, corroborating the hypothesis tested. The leaf decomposition was reduced in litter removed plots. The litter human interference altered the potassium concentration in the vertical profile of the soil. Moisture also showed difference in wet and dry period.

The maintenance of organic is a consensus in annual crops and commercial forest stands. The greater litterfall produced by Eucalypt stand promote the input of organic matter in dystrophic soils such as the Cerrado. The benefits are essential to attest to the feasibility of fast growing species such as Eucalypt, which become a facilitating species in the recovery of legal reserve, as was foreseen in the latest changes in the Brazilian forest code.

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CAPÍTULO III*

Modelagem de biomassa e nutrientes em povoamento de eucalipto no Cerrado

Modeling of biomass and nutrients in *Eucalyptus* stand in the Cerrado

ABSTRACT

The prediction of biological processes, which involves growth and plant development, is possible through the adjustment of mathematical models. In the forest area, this tool assists in management practices, silviculture, harvesting, soil fertility and others. Diameter, basal area and height become predictors of volume and biomass estimates in forest stands. This work aimed to adjust nonlinear models for estimating biomass and nutrients of aerial biomass and roots in unmanaged Eucalypt stands established in Cerrado dystrophic soil. It was hypothesized that the models would be able to estimate the nutrients of the biomass above the soil and roots, after meeting the criteria of selection and validation. Through the analysis of statistical parameters and subsequent validation the Schumacher-Hall model was the one that presented the best fit for biomass and nutrients. This result confirmed the ability of the variables diameter, basal area and height to be predicted, thus corroborating the hypothesis tested. Estimating the amount of nutrients that the aerial biomass and roots, it was possible to have a better notion of the quality of the vegetal residues that remained in the soil. In dystrophic soils, as they occur in the Cerrado, these estimates become even more relevant.

Keywords: non-linear models, Schumacher-Hall, aerial biomass, eucalyptuculture.

**Este capítulo foi redigido, em português, com figuras e tabelas em inglês no formato de artigo, de acordo com as normas do periódico Scientia Forestalis: Qualis CAPES: B1; JCR (2017): 0,50.*

RESUMO

A predição de processos biológicos, que envolve crescimento e desenvolvimento vegetal é possível por meio do ajuste de modelos matemáticos. No âmbito florestal, essa ferramenta auxilia em práticas de manejo, silvicultura, colheita, fertilidade do solo entre outras. Diâmetro, área basal e altura passam a ser variáveis preditoras em estimativas de volume e biomassa em povoamentos florestais. O objetivo do presente trabalho foi de ajustar modelos não lineares para estimativa de biomassa e nutrientes da biomassa aérea e raízes em povoamento de eucalipto não manejado estabelecido em solo distrófico do Cerrado. Foi testada a hipótese de que os modelos seriam capazes de estimar os nutrientes da biomassa acima do solo e raízes, após atendimento dos critérios de seleção e validação. Por meio da análise de parâmetros estatísticos e posterior validação, o modelo Schumacher-Hall foi o que apresentou o melhor ajuste para biomassa e nutrientes. Esse resultado atestou a capacidade das variáveis diâmetro, área basal e altura serem preditoras, assim, corroborando a hipótese testada. Ao estimar a quantidade de nutrientes que a biomassa aérea e raízes possuem, foi possível ter uma melhor noção da qualidade dos resíduos vegetais que permaneceram no solo. Em solos distróficos, como ocorrem no Cerrado, essas estimativas tornam-se ainda mais relevantes.

Palavras-chave: modelos não lineares, Schumacher-Hall, biomassa aérea, eucaliptocultura.

1. INTRODUCTION

The possibility to predict phenomenon and biological standards, determining coefficients, and reducing the inherent costs of data collection, the modeling is an essential tool. In the forest area, the models provide information on better management techniques and silvicultural practices.

Basal area, diameter and height are described as independent variables and growth models comprise biological processes are able to predict response variables. Wood volume estimates (PEREIRA et al., 2016; PERTILLE et al., 2018) and aboveground biomass (MIGUEL et al., 2017; LANZARIN et al., 2018) are response variables in regression models.

Classified as linear and non-linear due to the additive pattern of the parameters, the choice of the best models is made through visual interpretation and analysis of statistical parameters. The plotting of observed data in function of the estimated, dispersion of the residues *versus* adjusted values (VANCLAY, 1994) frequency of distribution of error classes (PEREIRA et al., 2016) are the main visual interpretations.

Adjusted coefficient of determination, standard error estimated in percentage (MACHADO et al., 2008; ASSIS et al., 2015; PERTILLE et al., 2018) are the main statistical parameters evaluated to choose of the best model. The validation of the select model, which is done with part of the observed data (LEAL et al., 2015; CASTRO et al., 2016), also constitutes an important step in the modeling process.

Volume and biomass projections through model adjustments are well established in the management of forest stands. In the face of such prior knowledge, these models would be able to estimate the amount of nutrients in Eucalypt stand? The nutrient distribution along the Stem (VERÃO et al., 2016) and the efficiency in the use of then, mainly with the increase of the stand age, become important in biogeochemical cycling (BARROS et al., 2014).

At harvest, nutrients are removed by more than 45% of the total amount accumulated in total aboveground biomass, consequently, phosphorus and calcium may limit productivity in the next rotations (VIEIRA et al., 2015). Thus, the objective of this work was to test the adjustment of non-linear models to estimate biomass and nutrients in Eucalypt stand established in Cerrado (Brazilian Savanna) dystrophic Red Latosol (Oxisoil). It were tested the hypothesis that models would be able to estimate nutrients of the aboveground biomass and roots, after meeting the criteria of selection and validation.

2. MATERIAL AND METHODS

2.1. Study area

The study was conducted at Fazenda Água Limpa - FAL, which belongs to the University of Brasília and located in the Distrito Federal. Eucalypt stand was established in January 2010 (72 months), with a total area of 3.29 hectares. The clone I224, *Eucalyptus urophylla* S. T. Blake x *Eucalyptus grandis* Hill ex-Maiden, was planted at 3 x 2 m spacing.

Soil was described as dystrophic Red Latosol (Oxisoil). In the preparation before to planting was done the grinding and subsoiling at 40 cm of depth and fertilization in the planting line with the application of 100 g of super simple phosphate and plus 100 g of NPK (4-30-16) were applied. After 30 days of planting, cover fertilization was done with 100 g of NPK (20-0-20). Liming and supplemental fertilization with micronutrients was not done.

2.2. Data collect

The forest inventory was carried out using the simple random sampling process in forty parcels with dimensions of 10 x 10 m, totaling 550 trees. In each parcel, the diameter was obtained by diametric tape with DBH (Diameter at Breast Height) at 1.3 m. The heights were obtained using the Sunnto clinometer at 15 meters of distance in all trees.

The Smalian method was used in proportion to the number of diameter classes from the inventory to calculate tree volumes. A total of 40 trees with DBH ≥ 5 cm were harvested and the weight of compartments (e.g. leaves, branch, crown, stem and bark. Samples of all compartments were collected to determine the concentration of the following nutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). The P, K, Ca and Mg concentration in the leaves ware determinate by nitro-perchloric digestion and analyze at Inductive Coupling Plasma. Sulfuric digestion and distillation were used for N concentration by the Kjeldahl method.

The root collected was defined by calculating the class amplitude of inventory of 40 plots and executed on nine trees (three for each class) from the 40 that had been cubed. There were defined three diameter classes: suppressed (between 5 and 11 cm); medians (between 11.1 and 17 cm) dominants (between 17.1 and 23 cm).

Sampling of the radicular biomass in the stand was done by means of 10 circular monoliths with a medial diameter of 23 cm. In the work area of each tree, three depth intervals of (0-20, 20-40 and 40-60 cm) were stratified (GATTO et al., 2014). The monoliths were 50 cm away from the tree with four collection points in the perpendicular direction of the planting line and six parallels to the planting line. The screening roots was done by sieves with a mesh of 1 mm, drying with forced air ventilation in a greenhouse (65 ± 5 oC) until the constant weight of dry biomass. The N, P, K, Ca, Mg concentrations were also determined.

2.3. Volume estimate, biomass and nutrient amount

After harvester and weighing of 40 trees it was possible to proceed to the modeling of volume and biomass for the stand. The adjustment was done with 33 randomly selected trees; the remaining seven trees were used for the validation of the model through the "t" test for paired data. Thus, using the Schumacher-Hall model, two equations were obtained for volume and biomass prediction for each of the inventoried trees.

Using the equations obtained by the modeling, it has estimated volume and biomass, in m³ and Mg, for each of the inventory trees. From this information, it was possible to obtain the volume and biomass of the stand, in $m^3\ ha^{-1}$ and $Mg\ ha^{-1}$, and calculate the statistical parameters for the stand (Table 1).

Each inventory tree was allocated within one of the classes: dominant, median and suppressed, as described in the methodology of roots collected. By this information and the sum of the nutrient concentration of the compartments, whose sample trees were also separated by class, it was possible to determinate the average concentrations of each nutrient for each tree in the inventory.

Multiplying the average concentration of nutrient for class by the amount of biomass, the value of each nutrient in kg^{-1} was obtained for each tree of the inventory and the amount of nutrients in Mg ha^{-1} was calculated for the forty parcels. Finally, combining the information of volume, biomass, nutrients, basal area and average height, it was possible to model biomass and nutrients according to the variables DBH, basal area and height.

Table 1. Statistical parameters obtained through the forest inventory carried out in Eucalypt stands.
Tabela 1. Parâmetros estatísticos obtidos por meio do inventário florestal realizado em povoamento de eucalipto.

Parameters	Volume	Unit	Biomass	Unit
Mean	328.88	$m^3\ ha^{-1}$	181.405	Mg ha^{-1}
Variance	3385.654	$(m^3\ ha)^2$		$(Mg\ ha)^2$
Standard deviation	58.186	$m^3\ ha^{-1}$	32.582	Mg ha^{-1}
Coefficient of variation (%)	17.692	%	17.961	%
Variance of the mean	74.351	$(m^3\ ha)^2$	23.31	$(Mg\ ha)^2$
Standard error of mean	8.623	$m^3\ ha^{-1}$	4.828	Mg ha^{-1}
Absolute sample error	17.441	$m^3\ ha^{-1}$	9.766	Mg ha^{-1}
Sample relative error	5.303	%	5.384	%

2.4. Modeling of Biomass and nutrient

Through the information of biomass and respective amount of each nutrient in Mg ha^{-1} it was possible to obtain the sum of each portion of each variable. They were all submitted to Pearson's correlation analysis, which DBH, basal area and total height were defined as predictor variables (Table 2) and biomass and nutrients were dependent variables (Table 2).

Based on the correlation values between the predictive and independent variables, it was possible to choose which variables would compose the models. Basal area and total height were used in biomass adjustment, DBH and total height for nitrogen and only basal area for phosphorus, potassium, calcium and magnesium. Forty plots were used to modeling of biomass and nutrients, which 30 of them were used for the adjustment and the other 10 to the validation.

The non-linear regression models (Table 3) used to estimates were: Richards, Weibull and Schumacher-Hall (SCHUMACHER; HALL, 1933). The first model was proposed to insert biological implications in growth estimates of *Cucumis melo* L., a variety of melon (RICHARDS, 1959). The second has applicability to estimate the population growth of protozoa, size of a bean grain and strength capacity of Indian cotton fiber (WEIBULL; SWEDEN, 1951). The double entry model proposed by SCHUMACHER and HALL (1933) was proposed to estimate the wood volume based on the correlation between diameter and height.

Table 2. Pearson correlation matrix between the predictor variables (basal area, height and diameter at breast height) and dependent variables (biomass and micronutrients).
Tabela 2. Matriz de correlação de Pearson entre as variáveis preditoras (área basal, altura e diâmetro à altura do peito) e variáveis dependentes (biomassa e micronutrientes).

Variables	G^{I}	H^{II}	DBH^{III}	$Biomass^{IV}$	N^{V}	P^{VI}	K^{VII}	Ca^{VIII}	Mg^{IX}
G^{I}	1.00	0.45**	0.47**	0.97**	0.26^{ns}	0.84**	0.93**	0.90**	0.88**
H^{II}	0.45**	1.00	0.82**	0.59**	-0.55**	0.20^{ns}	0.34*	0.35*	0.28^{ns}
DBH^{III}	0.47**	0.82**	1.00	0.61**	-0.61**	0.01^{ns}	0.20^{ns}	0.19^{ns}	0.10^{ns}
$Biomass^{IV}$	0.97**	0.59**	0.61**	1.00	0.14^{ns}	0.73**	0.86**	0.82**	0.79**
N^{V}	0.26^{ns}	-0.55**	-0.61**	0.14^{ns}	1.00	0.49**	0.40**	0.35*	0.43**
P^{VI}	0.84**	0.20^{ns}	0.01^{ns}	0.73**	0.49**	1.00	0.98**	0.98**	0.99**
K^{VII}	0.93**	0.34*	0.20^{ns}	0.86**	0.40**	0.98**	1.00	0.99**	0.99**
Ca^{VIII}	0.90**	0.35*	0.19^{ns}	0.82**	0.35*	0.98**	0.99**	1.00	0.99**
Mg^{IX}	0.88**	0.28^{ns}	0.10^{ns}	0.79**	0.43**	0.99**	0.99**	0.99**	1.00

*p<0.05; **p<0.01; ns: non-significant;
^{I}Basal area (m^2 ha^{-1}); ^{II}Height (m); ^{III}Diameter at breast height (cm); ^{IV}Biomass (Mg ha^{-1}); ^{V}Nitrogen (Mg ha^{-1}); ^{VI}Phosphorus (Mg ha^{-1}); ^{VII}Potassium (Mg ha^{-1}); ^{VII}Calcium (Mg ha^{-1}); ^{IX}Magnesium (Mg ha^{-1}).

Table 3. Nonlinear models and their equations used estimate biomass and nutrients in Eucalypt stand.
Tabela 3. Modelos não lineares e respectivas equações utilizadas para estimar biomassa e nutrientes em plantio de eucalipto.

Model	Equation
Richards (RICHARDS, 1959)	$Y = \frac{\alpha}{(1+e^{\beta-\gamma X_1})^{1/\delta}}$ *
Weibull (WEIBULL; SWEDEN, 1951)	$Y = \alpha - \beta e^{-\gamma X_1^{\delta}}$ **
Schumacher-Hall (SCHUMACHER; HALL, 1933)	$Y = \alpha_0 . X_1^{\beta} . X_2^{\gamma}$ ***

**Y*= biomass: X_1= (Basal area*Height); *Y*= Nitrogen: X_1= (Diameter breast height* Height); *Y*= Phosphorus, Potassium, Calcium and Magnesium: X_1= Basal area.
***Y*= biomass: X_1= (Basal area*Height); *Y*= Nitrogen: X_1= (Diameter breast height* Height); *Y*= Phosphorus, Potassium, Calcium and Magnesium: X_1= Basal area.
****Y*= biomass: X_1= Basal area, X_2= Height; *Y*= Nitrogen: X_1= Diameter breast height, X_2= Height; *Y*= Phosphorus, Potassium, Calcium and Magnesium: X_1= Basal area; X_2= Height.

3. RESULTS

The percentage of N, P, K, Ca and Mg in each compartment of the trees showed the leaves have presented the highest percentage of nitrogen, phosphorus and potassium in relation to the other fractions (Table 4). The percentage of calcium and magnesium were higher in the bark compartment (Table 4).

Table 4. Mean of biomass and percentage of nutrients per compartment of trees planted in Eucalypt stand.
Tabela 4. Quantidade média de biomassa e porcentagem de nutriente por compartimento de árvores cubadas em plantio de eucalipto.

Compartiment	Mean biomass (Mg)	N	P	K	Ca	Mg
				(%)		
Leaves	0.011 (4.36%)	1.375	0.077	0.433	0.573	0.363
Branch	0.010 (4.26%)	0.460	0.039	0.318	0.322	0.169
Bark	0.029 (11.99%)	0.255	0.020	0.260	1.198	0.984
Crown wood	0.014 (5.58%)	0.091	0.008	0.103	0.099	0.019
Stem wood	0.177 (72.15%)	0.084	0.002	0.039	0.056	0.005
Roots	0.004 (1.66%)	0.292	0.024	0.085	0.307	0.083
Total	0.246 (100%)	2.557	0.170	1.238	2.555	1.623

The non-linear models tested were able to estimate the depended variables. The statistical parameters used to choose the best models such as correlation of coefficient and estimated standard error, presented similar values for biomass (Table 5), N (Table 6), P (Table 7), K (Table 8), Ca (Table 9) and Mg (Table 10) estimates.

The visual presentation of the ratio of observed and estimated data, the plot of the residuals in percentage in function of the observed data and the frequency of the distribution of the error classes have contributed to the choice of the best adjustment. Thus, Schumacher-Hall was considered the best model for all the estimated variables, presenting a distribution frequency concentrated in the lowest error classes (Figures 1, 2, 3, 4, 5 and 6).

The standard error in percentage resulting from the adjustments has presented the lowest value for biomass estimative (Table 5), and nitrogen was the nutrient presented the largest error (Table 6). The visual interpretation of the residues in percentage in function of the observed data has showed the adjusted values for nutrients were slightly overestimated (Figures 2, 3, 4, 5 and 6).

This pattern, which N, P, K, Ca and Mg showed to overestimate, was also verified by means of the negative percentage of aggregate difference between observed and estimated values (Table 11). Nevertheless, the observed and estimated values for biomass and nutrients did not present statistical difference through the "t" test for paired data used to validate the Schumacher-Hall model (Table 11).

Table 5. Statistical parameters of the nonlinear models obtained in the adjustment of total biomass in Eucalypt stand.

Tabela 5. Parâmetros estatísticos dos modelos não lineares obtidos no ajuste de biomassa total em povoamento de eucalipto.

Model	α*	β*	γ*	δ*	Syx** (Mg ha^{-1})	Syx*** (%)	r****
Richards	304.492	-2.984	0.000	0.034	4.966	2.701	0.991
Weibull	335.095	271.007	0.000	1.099	4.930	2.682	0.991
Schumacher-Hall	1.282	1.013	0.504	-	4.934	2.684	0.991

*Coefficients; **Estimated standard error; ***Standard error of estimate in percentage; **** Correlation Coefficient.

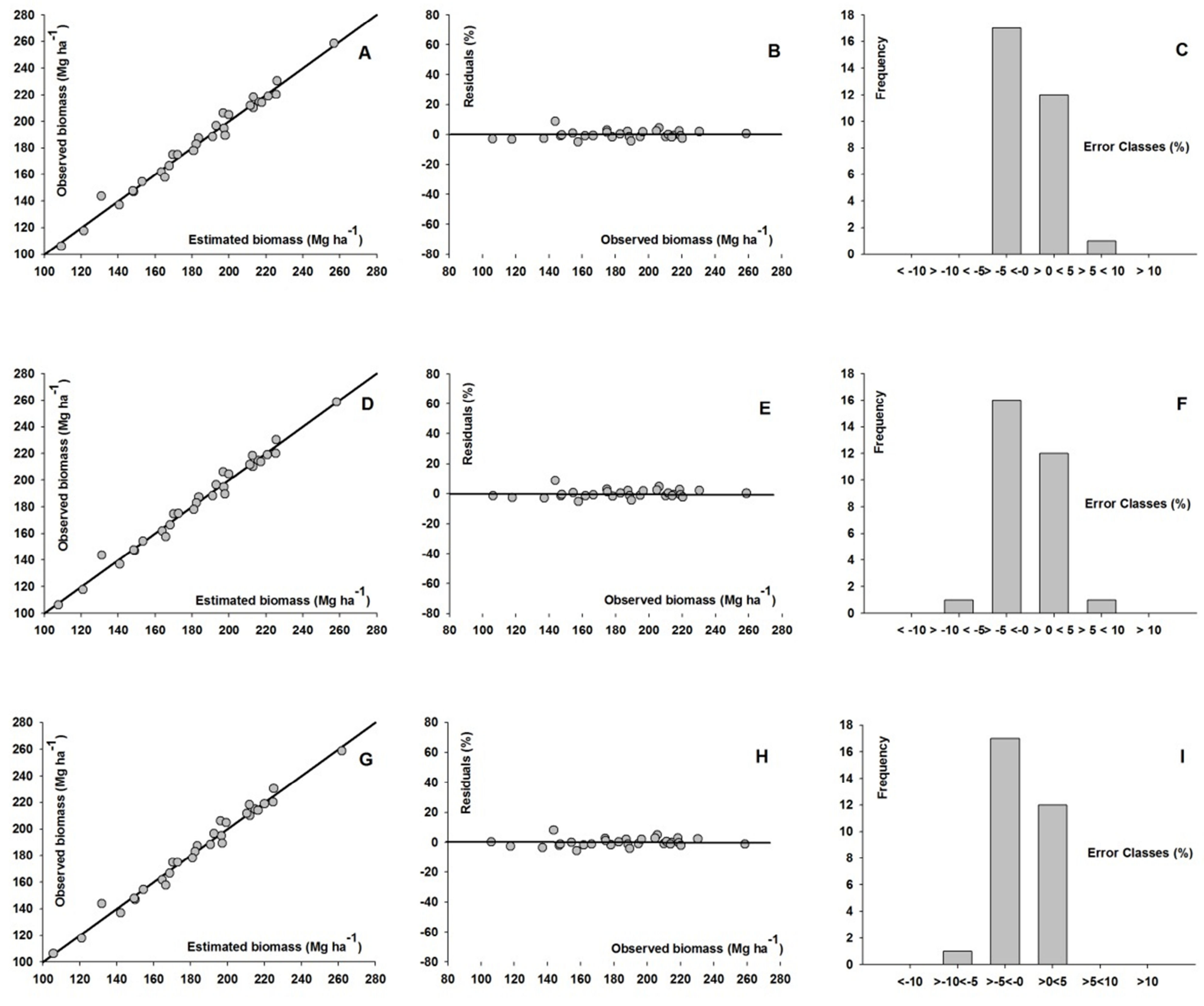

Figure 1. Dispersion of estimated value by observed value, dispersion of residues and distribution in error classes obtained for the biomass adjustments (Mg ha^{-1}) using non-linear models. Where A, B, and C refer to the Richards model; D, E and F to the Weibull model; G, H and I to the Schumacher-Hall model.

Figura 1. Dispersão de valor estimado por valor observado, dispersão de resíduos e distribuição em classes de erro obtidos para os ajustes biomassa (Mg ha^{-1}) utilizando modelos não lineares. Em que A, B e C são referentes ao modelo de Richards; D, E e F ao modelo de Weibull; G, H e I ao modelo Schumacher-Hall.

Table 6. Statistical parameters of the nonlinear models obtained in the adjustment of the amount of nitrogen in Eucalypt stand.
Tabela 6. Parâmetros estatísticos dos modelos não lineares obtidos no ajuste de quantidade de nitrogênio em povoamento de eucalipto.

Model	α*	β*	γ*	δ*	Syx** (Mg ha^{-1})	Syx*** (%)	r****
Richards	4.600	-3.213	-0.011	2.538	0.547	17.581	0.661
Weibull	4.157	6.601	12476.673	-1.502	0.547	17.578	0.661
Schumacher-Hall	256.475	-1.288	-0.283	-	0.546	17.525	0.648

*Coefficients; **Estimated standard error; ***Standard error of estimate in percentage; **** Correlation Coefficient.

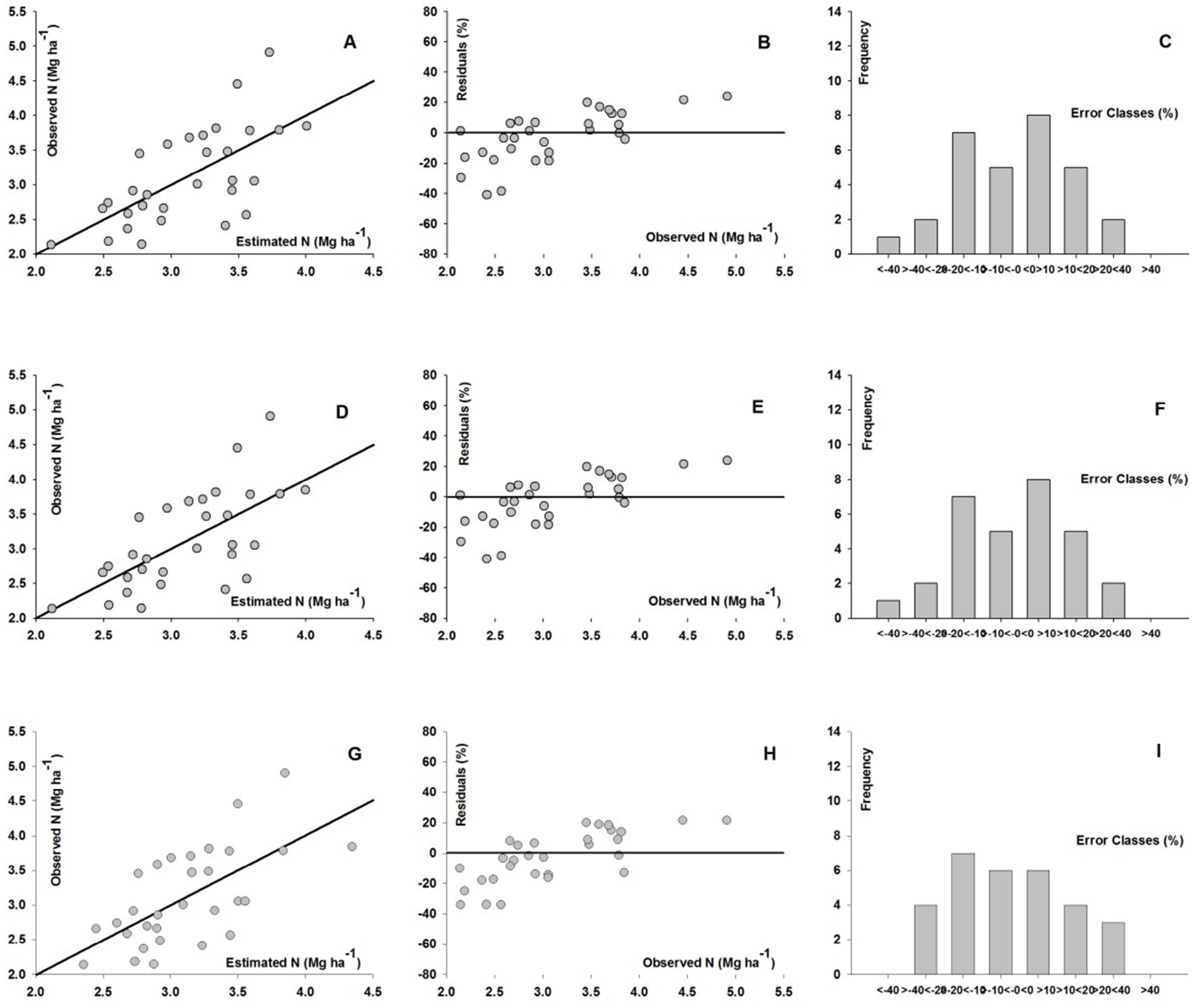

Figure 2. Dispersion of estimated value by observed value, dispersion of residues and distribution in error classes obtained for the nitrogen adjustments (Mg ha^{-1}) using non-linear models. Where A, B, and C refer to the Richards model; D, E and F to the Weibull model; G, H and I to the Schumacher-Hall model.
Figura 2. Dispersão de valor estimado por valor observado, dispersão de resíduos e distribuição em classes de erro obtidos para os ajustes de nitrogênio (Mg ha^{-1}) utilizando modelos não lineares. Em que A, B e C são referentes ao modelo de Richards; D, E e F ao modelo de Weibull; G, H e I ao modelo Schumacher-Hall.

Table 7. Statistical parameters of the nonlinear models obtained in the adjustment of the amount of phosphorus in Eucalypt stand.
Tabela 7. Parâmetros estatísticos dos modelos não lineares obtidos no ajuste de quantidade de fósforo em povoamento de eucalipto.

Model	α*	β*	γ*	δ*	Syx** (Mg ha^{-1})	Syx*** (%)	r****
Richards	0.650	4.142	0.054	1.927	0.014	8.386	0.840
Weibull	1.407	1.319	0.000	1.683	0.014	8.388	0.840
Schumacher-Hall	0.048	0.884.	-0.562	-	0.012	7.214	0.880

*Coefficients; **Estimated standard error; ***Standard error of estimate in percentage; **** Correlation Coefficient.

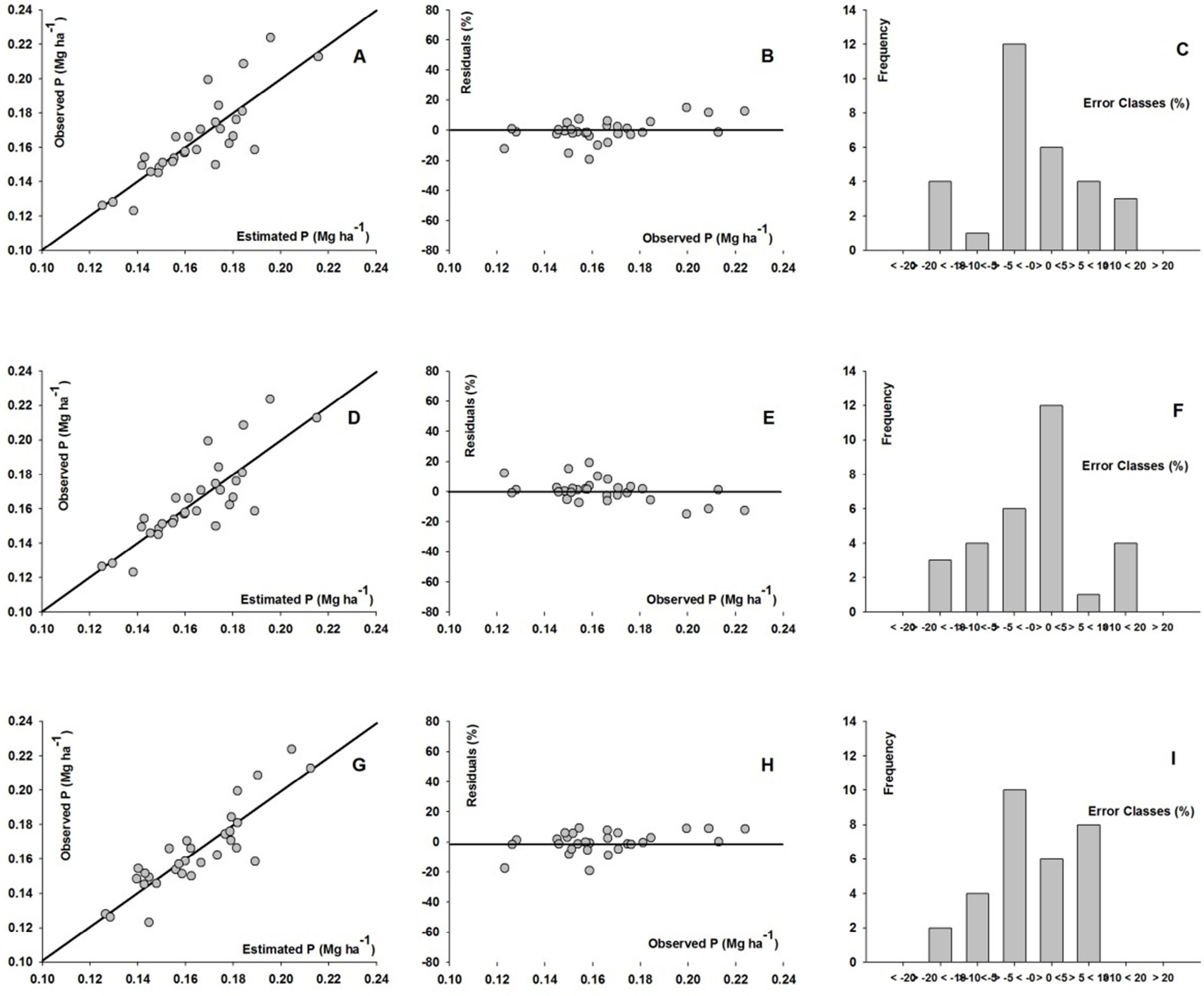

Figure 3. Dispersion of estimated value by observed value, dispersion of residues and distribution in error classes obtained for the phosphorus adjustments (Mg ha^{-1}) using non-linear models. Where A, B, and C refer to the Richards model; D, E and F to the Weibull model; G, H and I to the Schumacher-Hall model.
Figura 3. Dispersão de valor estimado por valor observado, dispersão de resíduos e distribuição em classes de erro obtidos para os ajustes de fósforo (Mg ha^{-1}) utilizando modelos não lineares. Em que A, B e C são referentes ao modelo de Richards; D, E e F ao modelo de Weibull; G, H e I ao modelo Schumacher-Hall.

Table 8. Statistical parameters of the nonlinear models obtained in the adjustment of the amount of potassium in Eucalypt stand.
Tabela 8. Parâmetros estatísticos dos modelos não lineares obtidos no ajuste de quantidade de potássio em povoamento de eucalipto.

Model	α*	β*	γ*	δ*	Syx** (Mg ha^{-1})	Syx*** (%)	r****
Richards	2.192	0.254	0.032	0.370	0.042	5.790	0.930
Weibull	3.664	3.397	0.001	1.444	0.042	5.789	0.930
Schumacher-Hall	0.085	0.906	-0.289	-	0.038	5.291	0.939

*Coefficients; **Estimated standard error; ***Standard error of estimate in percentage; **** Correlation Coefficient.

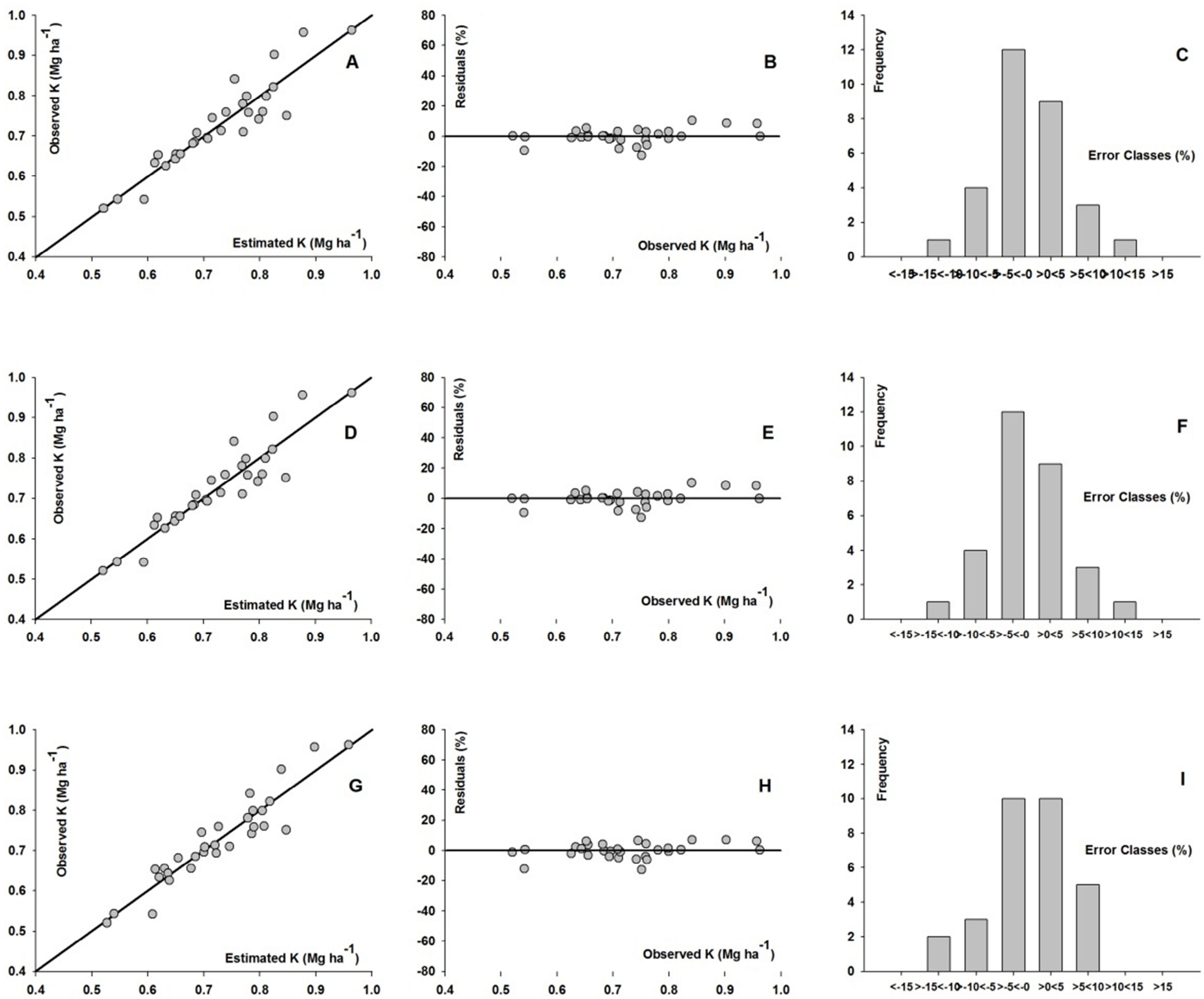

Figure 4. Dispersion of estimated value by observed value, dispersion of residues and distribution in error classes obtained for the potassium adjustments (Mg ha^{-1}) using non-linear models. Where A, B, and C refer to the Richards model; D, E and F to the Weibull model; G, H and I to the Schumacher-Hall model.
Figura 4. Dispersão de valor estimado por valor observado, dispersão de resíduos e distribuição em classes de erro obtidos para os ajustes de potássio (Mg ha^{-1}) utilizando modelos não lineares. Em que A, B e C são referentes ao modelo de Richards; D, E e F ao modelo de Weibull; G, H e I ao modelo Schumacher-Hall.

Table 9. Statistical parameters of the nonlinear models obtained in the adjustment of the amount of calcium in Eucalypt stand.
Tabela 9. Parâmetros estatísticos dos modelos não lineares obtidos no ajuste de quantidade de cálcio em povoamento de eucalipto.

Model	α*	β*	γ*	δ*	Syx** (Mg ha^{-1})	Syx*** (%)	r****
Richards	7.439	-0.557	0.030	0.199	0.171	6.827	0.906
Weibull	21.904	21.227	0.002	1.206	0.171	6.819	0.906
Schumacher-Hall	0.269	0.895	-0.248	-	0.162	6.445	0.913

*Coefficients; **Estimated standard error; ***Standard error of estimate in percentage; **** Correlation Coefficient.

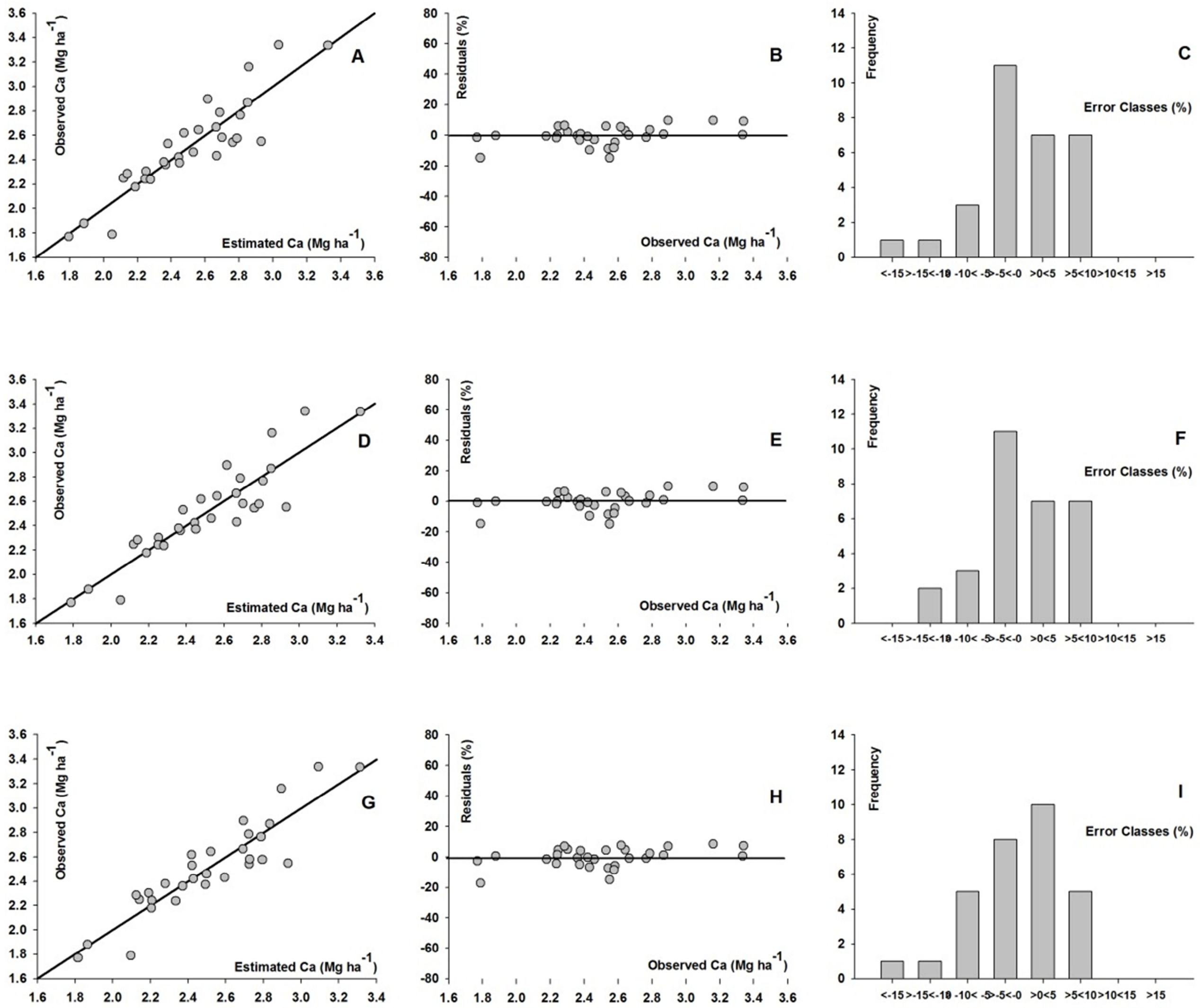

Figure 5. Dispersion of estimated value by observed value, dispersion of residues and distribution in error classes obtained for the calcium adjustments (Mg ha^{-1}) using non-linear models. Where A, B, and C refer to the Richards model; D, E and F to the Weibull model; G, H and I to the Schumacher-Hall model.
Figura 5. Dispersão de valor estimado por valor observado, dispersão de resíduos e distribuição em classes de erro obtidos para os ajustes de cálcio (Mg ha^{-1}) utilizando modelos não lineares. Em que A, B e C são referentes ao modelo de Richards; D, E e F ao modelo de Weibull; G, H e I ao modelo Schumacher-Hall.

Table 10. Statistical parameters of the nonlinear models obtained in the adjustment of the amount of magnesium in Eucalypt stands.

Tabela 10. Parâmetros estatísticos dos modelos não lineares obtidos no ajuste de quantidade de magnésio em povoamento de eucalipto.

Model	α*	β*	γ*	δ*	Syx** (Mg ha^{-1})	Syx*** (%)	r****
Richards	2.296	0.463	0.032	0.444	0.055	7.202	0.887
Weibull	4.388	4.103	0.001	1.360	0.055	7.200	0.887
Schumacher-Hall	0.127	0.885	-0.381	-	0.050	6.506	0.905

*Coefficients; **Estimated standard error; ***Standard error of estimate in percentage; **** Correlation Coefficient.

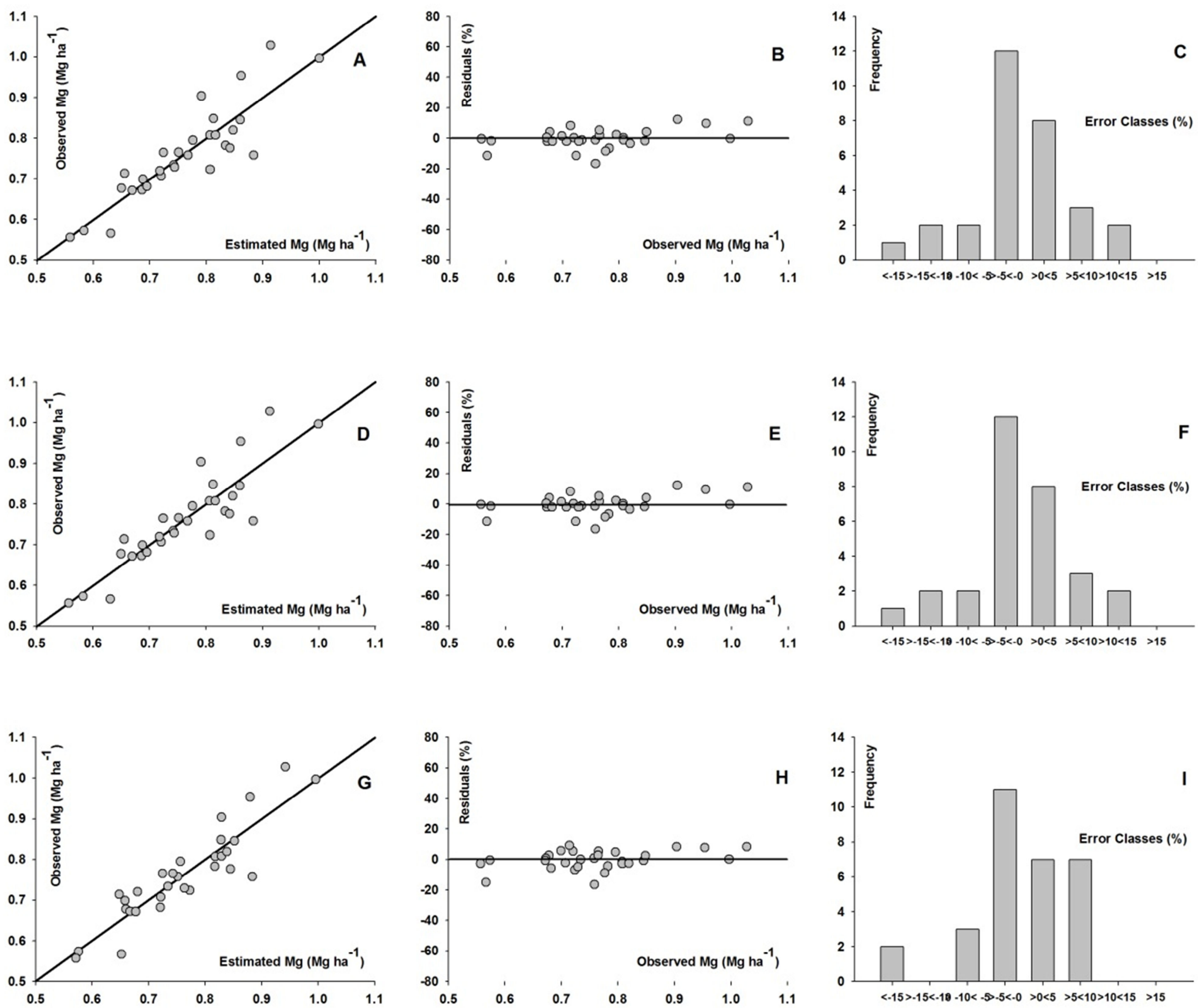

Figure 6. Dispersion of estimated value by observed value, dispersion of residues and distribution in error classes obtained for the magnesium adjustments (Mg ha^{-1}) using non-linear models. Where A, B, and C refer to the Richards model; D, E and F to the Weibull model; G, H and I to the Schumacher-Hall model.

Figura 6. Dispersão de valor estimado por valor observado, dispersão de resíduos e distribuição em classes de erro obtidos para os ajustes de magnésio (Mg ha^{-1}) utilizando modelos não lineares. Em que A, B e C são referentes ao modelo de Richards; D, E e F ao modelo de Weibull; G, H e I ao modelo Schumacher-Hall.

Table 11. Validation of the Shumacher-Hall model estimating biomass and nutrients in Eucalypt stand.
Tabela 11. Validação do modelo Shumacher-Hall estimativa de biomassa e nutrientes em plantio de eucalipto.

Variables (Mg ha^{-1})	$P_{calculated}$ *	Aggregated diference (%)
Biomass	0.89	0,43
Nitrogen	0.77	-0.57
Phosphorus	0.14	-4.09
Potassium	0.08	-3.28
Calcium	0.09	-3.78
Magnesium	0.70	-3.47

*Calculated by the t-Test for two samples assuming equivalent variances.

4. DISCUSSION

Being a constituent of several compounds in plants, such as nucleic acids and chlorophyll, the N becomes one of the elements absorbed in larger quantities by cultivated plants (CANTARELLA, 2007). The N is strictly linked to the raise of productivity in annual and perennial crops, however this macronutrient does not have a high assimilation by Eucalypt seedlings under nursery conditions (SOUZA et al., 2018). The increment of nitrogen fertilization in established planting is not able to increase the density of the wood as observed by Assis et al., (2018) in hybrid stand of *E. grandis* x E. *urophylla* in Minas Gerais state, Brazil.

The higher concentration of N in the leaf was also observed by Verão et al. (2016) in hybrid stand of *Eucalyptus grandis* x *Eucalyptus urophylla* in low fertility Argissolo in the northern state of Mato Grosso, Brazil. This pattern was also verified by Vieira et al. (2013); in stand of *Eucalyptus grandis* x *Eucalyptus urophylla* in the state of Rio Grande do Sul, also in Brazil. In addition to the leaves, bark and branches compartments have presented the highest percentage of macronutrients, which concentrate in newer structures (BARROS et al. 2014) because of the mobility and metabolic activity (DECHEN, NACHTIALL, 2007).

In general, non-linear models present good adjustments for biomass estimation in Eucalypt stand (SUBASINGUE, 2015; ASSIS et al., 2016; RIBEIRO et al., 2017). By diameter, Wernsdörfer et al. (2014) have also modeled nutrients in *Fagus sylvatica* settlement. However, in case of nutrients the estimates are also made indirectly, applying a logarithmic model to estimate the volume, establishing relation with the concentration of nutrients (RANCE et al., 2012). The product of the average concentration of nutrients and biomass is also used to quantify nutrients (DICK et al., 2016).

Even the methodological distinctions in biomass and nutrient estimates, the statistical and visual parameters resulting from the adjustments are were adequate to choose the best model. The ratio between residues and observed variables (MIGUEL et al., 2017), the aggregate difference (MACHADO et al., 2008) and the dispersion of the observed value for the estimated value (PIÑEIRO et al., 2008) attested the efficacy of all models tested in study.

The interpretation of these parameters was essential to choose the Schumacher-Hall model as the best for biomass and nutrient estimation. This model, which is a double entry, is well established in forestry scope to volume estimate (RÉ et al., 2015, PEREIRA et al., 2016; PERTILLE et al., 2018) and biomass (LIMA et al., 2016; LANZARIN et al., 2018). Although the Richards and Weibull's models present biological interpretations, population dynamics and growth over time (FLEMING, 2001; ANTHONY et al., 2018; TELEKEN et al., 2018), Campos and Leite (2009) highlight the Schumacher and Hall's model results in less biased estimates.

Even the nutrients presenting good statistical parameters, the percentage of standard error of the adjustments was higher in comparison to the biomass. Thais factor may be associated mainly with the mobility and distribution of some nutrients along the stem (SAIDELLES et al., 2010). Téo et al. (2009) showed mathematical models, traditionally used for volume estimates in forest area, did not present a satisfactory performance to estimate the micronutrient content in individuals of *Mimosa scabrella*. The authors have attributed this result to the distinctions of site conditions and age of the sampled individuals.

In case of nitrogen, the inherent complexity of its cycle, which according to Wink et al. (2015) is influenced by several factors such as losses in aboveground biomass or translocation of N to the soil through the root system (CANTARELLA, 2007), it has justified by the highest percentage of estimated standard error in comparison with other nutrients. The difficulty in determining N remains even after the litterfall. The plant residue quality, microbial activity and the carbon/nitrogen ratio (BARRETO et al., 2010; BARBOSA et al., 2017) are variables that may influence the adjustment for nitrogen.

Nevertheless, there are models designed for forest ecosystems capable of simulating biogeochemical dynamics in response to environmental changes in forest ecosystems (ZANCHI et al., 2014; YU et al., 2018). The non-linear forest ecosystem model ForSAFE has reproduced correctly chemical aspects of soil water, aboveground biomass, N and P concentrations of coniferous forest

(YU et al., 2018). The concentration and distribution of Al, Ca, Cl, K, Mg and Mn in distinct fractions of the aboveground biomass in pine forest was estimated by a compartment model (GIELEN et al., 2016). Thus, according to the authors, the studied elements followed the same pathways inside the tree, allowing an understanding of the cycling of nutrients in forest ecosystems that suffered radioactive accidents.

5. CONCLUSION

Non-linear models tested to estimate biomass and nutrients by DBH, basal area and height variables were effective in Eucalypt stand. Thus, the tested hypothesis, the models would be able to predict the amount of nutrients of the aboveground biomass was corroborated.

All tested models have presented good adjustments, but the Schumacher-Hall was the best in estimate of N, P, K, Ca and Mg of aboveground biomass and roots. It is important to analyze, both visual plotting and the statistical parameters of the adjustments.

By the prediction of biomass and nutrients it is possible to estimate the amount of nutrients contained in Eucalypt stand. In case of second conduction rotation, the coefficients obtained through the adjustments are able to know about the input of nutrients and carbon in the soil system. Considering the dystrophic character of Cerrado soils, this knowledge becomes more relevant.

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CONSIDERAÇÕES FINAIS

Os resultados obtidos nesta tese mostraram aspectos importantes da relação solo-planta em povoamento eucalipto em solo distrófico do Cerrado. O monitoramento mensal de produção, acúmulo e decomposição de serapilheira, embora dispendioso para coletar, foi a maneira mais coerente e completa de avaliar a entrada nutrientes e as possíveis mudanças nas propriedades físico-químicas solo.

No primeiro capítulo, foi destacado que povoamentos de eucalipto apresentam alta produção e acúmulo de serapilheira, porém com uma decomposição lenta. Pensando em retorno rápido de nutrientes para o solo, talvez esse padrão não fosse tão vantajoso. Entretanto, ao considerar a manutenção das propriedades físicas e a proteção do solo, a recalcitrância desse resíduo, ao longo do tempo pode garantir a manutenção que assegura o crescimento de plantas, especialmente em solos distróficos que predominam no Cerrado.

De maneira imediata, a remoção da camada de serapilheira do solo acarretou em aumento no tempo estimado de decomposição foliar, alterou a concentração de potássio ao longo do perfil vertical do solo e ainda diminui a capacidade de manutenção da umidade do solo no período mais seco do ano. As conclusões, que foram obtidas no segundo capítulo referenciam a importância da proteção do solo por meio da permanência de resíduos orgânicos.

As recentes alterações no código florestal possibilitam o plantio de até 50% de espécies exóticas em área de reserva legal e preservação permanente a serem recuperadas. Com essa nova previsão legal a interação entre espécies exóticas e nativas será alvo de bastantes questionamentos. Por isso, ao estimar por meio de modelagem, biomassa e nutrientes em povoamento de eucalipto foi possível ter uma aferir não só de quantidade mais também da qualidade do material que é aportado no solo. Assim, o terceiro e último capítulo dessa tese mostrou ser possível não só ajustar modelos já consagrados nas estimativas de biomassa e volume, mas também possibilitam estimativas de caráter nutricional.

Espera-se que os resultados obtidos neste documento contribuam para a tomada de decisão no âmbito acadêmico, jurídico-ambiental e que principalmente alcance a comunidade do agronegócio. É um verdadeiro desafio para qualquer pesquisador transcender os limites da academia e vislumbrar sua pesquisa sendo utilizada de forma prática. Que os interesses pessoais, ideológicos e políticos não impeçam a comunidade científica possa dialogar com a sociedade civil de forma racional e que a sustentabilidade vai muito além de um estilo de vida. Ser sustentável é ter responsabilidade com futuro da humanidade.