

# EFFECT OF INCREASING THE FERTILIZER DOSE ON BIOMASS PRODUCTION OF *Eucalyptus dunnii* Maiden

Grasiele Dick<sup>1</sup>\*, Mauro Valdir Schumacher<sup>2</sup>, Elias Frank de Araujo<sup>3</sup>

<sup>1</sup>Federal University of Santa Maria, Post-Graduate Program of Forestry Engineering, Santa Maria, Rio Grande do Sul state, Brazil - email [grasidick@hotmail.com](mailto:grasidick@hotmail.com)

<sup>2</sup>Federal University of Santa Maria, Department of Forest Sciences, Santa Maria, Rio Grande do Sul state, Brazil - e-mail [mauro.schumacher@ufsm.br](mailto:mauro.schumacher@ufsm.br)

<sup>3</sup>CMPC Guaíba unit, Guaíba, Rio Grande do Sul state, Brazil - e-mail [efaraujo@cmprcs.com.br](mailto:efaraujo@cmprcs.com.br)

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## Resumo

### *Efeito do aumento da dose de fertilizante na produção de biomassa de Eucalyptus dunnii Maiden*

Com a recente expansão do cultivo de *Eucalyptus dunnii* Maiden na região central do Rio Grande do Sul, surgem questionamentos recorrentes, tanto da pesquisa quanto da silvicultura operacional, especialmente em relação à fertilização mineral. O objetivo deste estudo foi testar se há efeito do aumento da dose de fertilizante (150, 225 e 450 g planta<sup>-1</sup> de N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, nas proporções 24:00:24) na produção de biomassa, estoque de carbono e nutrientes em árvores de *Eucalyptus dunnii* cultivadas em Cambissolo na região central do Rio Grande do Sul, Brasil. Este estudo revelou que não há efeito do aumento na dose de fertilizante sobre o acúmulo de biomassa, carbono e nutrientes nos componentes das árvores de *Eucalyptus dunnii*. Os nutrientes estiveram mais concentrados nas folhas; na madeira do tronco houve maior estoque de carbono e potássio; nos galhos e na casa do tronco o cálcio predominou. Em função da expressiva produção de biomassa, independentemente da dose de fertilizante, visando a redução de custos e impactos ambientais, recomenda-se aplicar a fertilização mineral com 150 g planta<sup>-1</sup> de N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, nas proporções 24:00:24, nas plantações de *Eucalyptus dunnii* cultivadas em Cambissolo na região central do Rio Grande do Sul, Brasil.

*Palavras-chave:* Silvicultura; Nutrição florestal; Ciclagem de nutrientes; Estoque de carbono e nutrientes.

## Abstract

With the recent expansion of *Eucalyptus dunnii* Maiden cultivation in central region of Rio Grande do Sul state, recurrent questions arise from both research and operational silviculture, especially in relation to mineral fertilization. The objective of this study was to test the effect of fertilizer dose increase (150, 225 and 450 g plant<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion) on the biomass production, carbon stock and nutrients in *Eucalyptus dunnii* trees cultivated in dystrophic Inceptisol, in central region of Rio Grande do Sul state, Brazil. This study revealed that there is no effect of the fertilizer dose increase on the accumulation of biomass, carbon and nutrients in components of *Eucalyptus dunnii* trees. The nutrients were more concentrated in leaves; in stemwood there was greater stock of carbon and potassium; in branches and stembark the calcium prevailed. Due to the significant biomass production, regardless of fertilizer dose, aiming at reducing costs and environmental impacts, it is recommended to apply mineral fertilization with 150 g plant<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion, in *Eucalyptus dunnii* stand cultivated in dystrophic Inceptisol, in central region of Rio Grande do Sul state, Brazil.

*Keywords:* Silviculture; Forest nutrition; Nutrient cycling; Carbon and nutrients stock.

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## INTRODUCTION

In the world there are 290.4 million hectares occupied with forest stands, where 20 million of these are *Eucalyptus* plantations (FAO, 2016). In Brazil, until 2016, the area with planted trees was 7.84 million hectares, an increase of 0.5% compared to 2015, due exclusively to the expansion of eucalyptus cultivation, which represents 71.9% of silviculture area in the country (IBÁ, 2017). In recent years, there has been an expansion of silviculture, mainly in the central and western regions of Rio Grande do Sul state, in Pampa biome and, among the planted species, *Eucalyptus dunnii* Maiden stands out. Due to ecophysiological plasticity and cold tolerance, the species

adapted to edaphoclimatic conditions of the region, and stemwood biomass is destined mainly to cellulose and energy industry.

In this expanding forest scenario, where the highest biomass production is expected in plantations in a short period of time, fertilization management becomes indispensable. Due to the intense removal of nutrients by biomass harvesting, higher doses of corrective fertilization are needed to reestablish nutritional balance and ensure forest productivity in coming cycles of (GUIMARÃES *et al.*, 2015). However, there is a lot to know about the effects of fertilizer doses on biomass production in different eucalyptus species grown in most different sites. Many species, including *Eucalyptus dunnii*, have not yet been studied as to the responses promoted by manipulation of mineral fertilization, and most studies were conducted in *Eucalyptus grandis*, cultivated in southeastern region of Brazil (SILVA *et al.*, 2013; FARIA *et al.*, 2002).

These researches are necessary and important in a scenario where the economically viable forest production is aimed, since the high cost of fertilizers can hinder forest activity. At the same time, environmental issues should also be considered, as the excess or incorrect application of fertilizer can cause serious damage from soil contamination, loss of diversity, eutrophication of watercourses caused by excess nitrogen (nitrate), phosphorus, among other impacts, which generate harsh criticism of silviculture activities (COSTA *et al.*, 2016). On the other hand, depending on the purpose of raw material using of forest plantations, silviculture may be a viable alternative to mitigate the increase in concentration of CO<sub>2</sub> released into atmosphere via carbon fixation, which is stored in different components of tree biomass (GATTO *et al.*, 2011; TURGUILHO *et al.*, 2010; LOPES and ARANHA, 2006).

In *Eucalyptus* silviculture, fertilization can influence the biomass production and nutrient allocation (SILVA *et al.*, 2013), added to climatic conditions, location, water availability (STAPE *et al.*, 2010), age, species (LACLAU *et al.*, 2000) and soil class (VIERA *et al.*, 2017). In this study, the hypothesis that the fertilizer dose does not alter the biomass production, carbon stock and nutrients in *Eucalyptus dunnii* trees was tested. The objective of this study was to test whether there is an effect of increasing the fertilizer dose (150, 225 and 450 g plant<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion) in biomass production, carbon stock and nutrients in *Eucalyptus dunnii* trees, grown in dystrophic Inceptisol in central region of Rio Grande do Sul state, Brazil.

## MATERIAL AND METHODS

### Study site

This study was carried out in municipality of São Gabriel, central region of Rio Grande do Sul state, Pampa biome, Brazil. The average altitude in the area is 114 meters above the sea level and plan relief. The soil type is dystrophic Inceptisol, with low fertility (Table 1), medium depth, presenting in profile a sequence of horizons A (0 to 40 cm deep), Bi (40 to 60 cm) and C (from 60 cm), medium texture and density varying between 1.45 to 1.58 g cm<sup>-3</sup>.

Table 1. Soil characteristics in *Eucalyptus dunnii* plantation before fertilization.

Tabela 1. Características do solo em plantação de *Eucalyptus dunnii* antes da fertilização.

Depth	Clay	SOM	pH	Al	Ca	Mg	t	P*	K	V	m
cm	%	%	(H <sub>2</sub> O)	----- cmol <sub>c</sub> dm <sup>-3</sup> -----				--mg dm <sup>-3</sup> --	----%----		
0 to 20	12	1.4	4.5	0.8	0.40	0.13	1.6	32.8	63.9	43.1	54.2
20 to 40	12	1.1	4.7	0.9	0.32	0.06	1.4	7.4	56.2	37.1	63.0
40 to 60	16	1.0	4.7	0.8	0.32	0.06	1.3	4.8	59.5	40.8	59.4
60 to 80	16	0.8	4.7	1.1	0.34	0.05	1.6	2.2	47.9	31.9	68.5

Where: Soil Organic Matter (OM); Hydrogen potential (pH); aluminum (Al); calcium (Ca); magnesium (Mg) t; Effective cation exchange capacity (t); phosphorus - P\* extracted by Melich1 method; potassium (K); base saturation (V); saturation by aluminum (m).

The climate of the region, according to Köppen classification, is humid subtropical Cfa type, with an average temperature of warmest month exceeding 22°C and in coldest month it varies from -3°C to 18°C, with an incidence of frosts in winter season; rainfall is well distributed over the months, without periods of drought, and annual volume ranges from 1,600 to 1,900 mm year<sup>-1</sup> (ALVARES *et al.*, 2013). During study period, the total

volume of rainfall in site was 1,782.3 mm, with the lowest volume in February (23.1 mm) and maximum in October (314.3 mm) and December (307.3 mm).

## Experimental design

The experiment was carried out in a reform site cultivated with *Eucalyptus dunnii* (central geographical coordinates of 30° 30' 12" S and 54° 10' 0.8" W), where the residues from previous harvest were kept on the soil. In order to soil tillage between the lines, subsoiling was carried out with three stems up to 50 cm deep. Planting fertilization of 2.0 Mg ha<sup>-1</sup> of dolomitic limestone was applied in total area, and 400 kg ha<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 10:27:10 proportion, applied in pit. Seminal seedlings were planted in May 2014, at a spacing of 3.0 m x 1.7 m.

Designed in nine sample units, with 20 m x 30 m each, the experiment was conducted in a completely randomized design, where in each unit there were approximately 30 trees. The choice of this design was due to the standardized planting fertilization and homogeneous conditions of fertility, soil depth and nutritional status of the trees, previously verified.

For cultivation of *Eucalyptus dunnii* in dystrophic Inceptisol in central region of Rio Grande do Sul state, Pampa biome, fertilization is essential and, through the NUTRICALC platform (BARROS *et al.*, 1995), if the dose of 150 g per plant<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion. This recommendation was based on analysis of nutrient stocks estimates in soil-plant system, which is necessary to reach the maximum expected productivity (40 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>). The treatments evaluated in experiment consisted of applying this recommendation (control - C0) and fertilizer additional dosages (Table 2). All treatments were applied on the same day, thrown over the soil, in crown area projection, at 14 months after planting. In month in which the fertilizer was applied, there was an incidence rainfall of 80 mm.

Table 2. Fertilizer doses applied in *Eucalyptus dunnii* plants.

Tabela 2. Doses de fertilizante aplicadas nas plantas de *Eucalyptus dunnii*.

Treatment	Recommendations	Dose
C0	N- P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O (recommendation) *	150 g plant <sup>-1</sup>
C1	C0 + 50% of recommendation	225 g plant <sup>-1</sup>
C2	C0 + 200% of recommendation	450 g plant <sup>-1</sup>

\*Dose recommended by the Nutricalc platform for the experiment conditions.

The evaluations of the effects of treatments were carried out at 36 months after planting, where double borders were considered in each sample unit. This procedure is necessary to isolate possible interactions (root system and fertilizer distribution) and data interference (influence of treatments applied on neighboring plots).

## Quantification of biomass, carbon stock and nutrients

For the sampling of above ground biomass, a previous inventory was carried out, where the values of diameter at breast height (DBH) of all trees in the experiment was measured. Based on this inventory, trees were selected with the average DBH values for each treatment, resulting in: 12.1, 12.7 and 12.8 cm in C0, C1 and C2, respectively. Then, three trees of medium DBH per treatment were sectioned at ground level. After cutting, the trees were divided into components: stemwood, stembark, branches and leaves, which were weighed in the field. After obtaining the wet weight, for subsequent determination of dry mass, three samples composed of 150 g each, from leaves and branches were collected. As for stemwood and stembark, discs were collected, removed after marking sampling points, distributed along the stem length, in median positions of the sections, resulting from division into three equal parts of it, which composed three samples of each component.

To obtain the dry mass, these samples were processed in laboratory, passing through drying in a circulation oven and renewing air, at 70°C, until reaching constant weight, with subsequent weighing on a precision scale (0.01 g), determining dry weight. Then, the samples were ground in a Willey mill with subsequent analytical determination of macronutrient concentrations. To determine the concentrations of calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P) and sulfur (S), was used a nitric-perchloric digestion (HNO<sub>3</sub> + HClO<sub>4</sub>, in 3:1 ratio), determined by spectrophotometry (TEDESCO *et al.*, 1995). The C and total N content were determined

with an elementary analyzer (Flash EA 1112 model, Thermo Finnigan, Milan, Italy, to determine C; Flash EA 1112, Thermo Electron Corporation, Bremen, Germany, to determine N).

To estimate *Eucalyptus dunnii* total biomass, the individual mass of each average DBH tree was multiplied by the total number of trees in sample unit and subsequently extrapolated per hectare (Mg ha<sup>-1</sup>). The carbon and nutrient stock, accumulated in each component of the tree, was calculated using the product between concentrations and respective biomass amounts obtained in each treatment.

## Data analysis

The variance homogeneity assumptions were verified, using the Bartlett test, and normality of errors, by Shapiro-Wilk, both at level of 5% error probability. Data on biomass, carbon stock and nutrient concentrations, in different components of biomass and between each of treatments, were subjected to analysis of variance (ANOVA) by test F, in a completely randomized design. With the F test significance, the means were compared using Tukey test, at the level of 5% error probability.

## RESULTS

### Biomass and carbon

There was no effect of the different fertilizer doses on biomass amount of *Eucalyptus dunnii*, which was 58.8 Mg ha<sup>-1</sup> on average. In all treatments, the allocation priority followed the order: stemwood > branches > stembark > leaves (Table 3). Together, the stemwood and branches correspond to more than 80% of the biomass. The treatments did not influence the carbon stock in biomass, which is 26.9 Mg ha<sup>-1</sup>, on average, an amount equivalent to 45.7% of the total biomass produced. In biomass components, carbon accumulation followed a decreasing order: stemwood > branches > leaves > stembark. The largest amount of carbon is stored in stemwood, as it is the component with greatest biomass; however, the highest concentration is in leaves (51% of C) and branches (46% of C), whereas, the carbon concentrations in stembark and stemwood are 43 and 45%, respectively.

Table 3. Biomass and carbon stock in *Eucalyptus dunnii* trees cultivated in central region of Rio Grande do Sul state, Brazil, after application of different fertilizer doses.

Tabela 3. Biomassa e estoque de carbono em árvores de *Eucalyptus dunnii* cultivadas na região central do Rio Grande do Sul, Brasil, após aplicação de diferentes doses de fertilizante.

	C0			C1			C2		
	C	B	Ac	C	B	Ac	C	B	Ac
	----- Mg ha <sup>-1</sup> -----			----- Mg ha <sup>-1</sup> -----			----- Mg ha <sup>-1</sup> -----		
			%			%			%
<sup>1</sup> L	2.7 <sup>n.s.</sup> (2.0)	5.3 <sup>n.s.</sup> (24.4)	9.4	2.6 (3.5)	5.1 (3.4)	8.5	2.8 (2.0)	5.3 (13.0)	8.8
B	3.1 (1.1)	6.7 (29.2)	11.9	4.3 (2.0)	9.2 (36.8)	15.3	3.2 (0.8)	7.1 (18.3)	11.8
Sb	1.8 (0.8)	4.2 (53.7)	7.5	2.5 (1.4)	5.7 (10.7)	9.5	2.7 (0.9)	6.5 (7.7)	10.8
Sw	18.1 (0.6)	39.9 (8.7)	71.2	18.2 (1.0)	40.0 (2.0)	66.7	18.8 (0.5)	41.3 (13.0)	68.6
<b>Total</b>	<b>25.7</b>	<b>56.1</b>	<b>100</b>	<b>27.6</b>	<b>60.0</b>	<b>100</b>	<b>27.5</b>	<b>60.2</b>	<b>100</b>

Where: <sup>1</sup>L = leaves; B = branches; Sb = stembark; Sw = stemwood; C = carbon; B = biomass; Ac = accumulated relative biomass in each component; Values in parentheses = coefficient of variation; \* ns = not significant for the tested levels; C0 = 150 g; C1 = 225 g; C2 = 450 g of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion, per plant.

### Nutrients in biomass

Nutrient concentrations varied between components of biomass, but did not differ depending on the fertilizer doses. Except for calcium, which is more concentrated in branches and stembark in C1 and C2, there was

a higher concentration of nutrients in leaves and lowest values were observed in stemwood, in all treatments (Table 4).

Table 4. Nutrients concentrations in biomass of *Eucalyptus dunnii* trees cultivated in central region of Rio Grande do Sul state, Brazil, before different fertilizer doses.

Tabela 4. Concentrações de nutrientes na biomassa de árvores de *Eucalyptus dunnii* cultivadas na região central do Rio Grande do Sul, Brasil, após aplicação de diferentes doses de fertilizante.

		N	P	K	Ca	Mg	S
		(g kg <sup>-1</sup> )					
C0	<sup>1</sup> L	18.40 a <sup>2*</sup> (12.14)	1.51 a (6.61)	7.00 a (14.39)	9.51 a (13.11)	2.65 a (2.76)	1.02 a (5.51)
	B	3.04 b (38.20)	0.30 c (24.13)	4.25 b (10.24)	11.10 a (11.50)	1.46 b (33.07)	0.28 b (0.35)
	Sb	3.36 b (23.81)	0.54 b (13.71)	6.64 a (12.17)	12.47 a (19.62)	2.82 a (19.82)	0.30 b (11.47)
	Sw	0.72 c (83.86)	0.36 c (26.20)	2.12 c (24.83)	0.83 b (28.34)	0.83 b (22.53)	0.19 c (18.93)
	L	17.62 a (15.35)	1.40 a (14.28)	8.74 a (38.81)	8.96 b (19.43)	2.65 a (5.51)	1.03 a (9.95)
C1	B	3.91 b (41.45)	0.41 bc (22.16)	5.05 b (37.55)	9.32 b (17.98)	1.56 b (8.00)	0.34 b (7.10)
	Sb	3.19 b (43.33)	0.59 b (18.63)	7.14 ab (10.93)	13.96 a (23.71)	2.81 a (19.85)	0.33 b (14.59)
	Sw	0.96 c (67.07)	0.28 c (33.72)	1.88 c (13.89)	0.79 c (12.00)	0.73 c (27.21)	0.19 c (12.80)
	L	20.40 a (7.95)	1.23 a (3.53)	7.00 ab (2.59)	7.51 b (8.51)	2.69 ab (1.42)	1.06 a (6.09)
C2	B	2.64 bc (22.37)	0.31 c (36.53)	4.98 b (27.30)	11.56 a (32.24)	1.91 b (48.23)	0.33 b (16.52)
	Sb	3.84 b (35.15)	0.56 b (13.93)	7.47 a (15.54)	13.66 a (14.83)	2.81 a (14.89)	0.30 b (6.35)
	Sw	0.84 c (74.43)	0.28 c (32.79)	2.16 c (17.94)	0.76 c (26.42)	0.88 c (12.81)	0.19 c (6.98)

Where: <sup>1</sup>L = leaves; B = branches; Sb = stembark; Sw = stemwood; Value in parentheses: Coefficient of variation; <sup>2</sup>Average concentrations of nutrients in biomass components, followed by the same letter in column, do not differ by Tukey test at 5% probability; \*not significant for the tested levels of nutrient concentrations in biomass components in different treatments; C0 = 150 g; C1 = 225 g; C2 = 450 g of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion, per plant; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur.

In relation to other nutrients, phosphorus and sulfur are in lower concentrations, in all components of biomass. It is observed that, in mineral composition of leaves, nitrogen presented a higher concentration (N > Ca > K > Mg > P > S), in stemwood, potassium (K > N > Ca > Mg > P > S) and calcium is more concentrated in branches (Ca > K > N > Mg > P > S) and stembark (Ca > K > N > Mg > P > S).

The largest amounts of nutrients (except N and Ca) are stored in stemwood, in all treatments (Table 5). The trend of nutrient stock in total biomass followed the decreasing order: Ca > K > N > Mg > P > S. There is a greater amount of K in stemwood, whose accumulation corresponded to 47%, 36% and 42% of total nutrients contained in biomass of the trees, when fertilized with doses C0, C1 and C2, respectively.

Table 5. Amounts of nutrients in biomass of *Eucalyptus dunnii* trees cultivated in central region of Rio Grande do Sul state, Brazil, before different fertilizer doses.

Tabela 5. Quantidade de nutrientes na biomassa de árvores de *Eucalyptus dunnii* cultivadas na região central do Rio Grande do Sul, Brasil, após aplicação de diferentes doses de fertilizante.

		N	P	K	Ca	Mg	S
		(kg ha <sup>-1</sup> )					
C0	<sup>1</sup> L	97.5	8.0	37.1	50.4	14.1	5.4
	B	20.4	2.0	28.5	74.4	9.8	1.9
	Sb	14.1	2.2	27.9	52.4	11.9	1.3
	Sw	28.7	14.3	84.4	33.2	33.8	7.8
	<b>Total</b>	160.7	26.6	177.9	210.4	69.5	16.3
C1	L	87.8	7.1	44.6	45.7	13.5	5.3
	B	36.0	3.8	46.5	85.7	14.4	3.2
	Sb	18.2	3.3	40.7	79.6	16.0	1.9
	Sw	38.4	11.2	75.2	31.6	29.4	7.5
	<b>Total</b>	180.3	25.5	207.0	242.6	73.3	17.8
C2	L	108.1	6.5	37.1	39.8	14.3	5.6
	B	18.7	2.2	35.4	82.1	13.6	2.3
	Sb	25.0	3.7	48.5	88.8	18.3	1.9
	Sw	34.7	11.7	89.2	31.3	36.5	7.7
	<b>Total</b>	186.5	24.1	210.2	241.9	82.6	17.6

Where: <sup>1</sup>L = leaves; B = branches; Sb = stembark; Sw = stemwood; C0 = 150 g; C1 = 225 g; C2 = 450 g of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion, per plant; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur.

In all treatments, the amounts of sulfur and potassium in biomass components are lower. In leaves, the nitrogen stock was greater than 85 kg ha<sup>-1</sup>, reaching more than 100 kg ha<sup>-1</sup> when the trees are fertilized with dose of 450 g plant<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion (C2). With C2 treatment, the potassium stock in stembark was 73.8% higher than that observed in C0 and, this fertilizer dosage promoted a greater amount of N, K and Mg in total biomass. Together the branches and stembark represent 60.3%, 68.1% and 70.7% of calcium amount in total biomass of the trees, fertilized with doses C0, C1 and C2, respectively.

## DISCUSSION

### Biomass and carbon

In all treatments, the biomass amount produced at 36 months of *Eucalyptus dunnii* trees was significant (Table 3). Since the different fertilizer dosages did not influence the biomass production and, aiming at reducing costs and risks of environmental impacts caused by excess of minerals in soil (COSTA *et al.*, 2016), the application can be carried out 150 g plant<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion (C0), for cultivation of *Eucalyptus dunnii* in dystrophic Inceptisol, in central region of Rio Grande do Sul state.

The biomass production of *Eucalyptus dunnii* trees can be considered high, based on the comparison between the cultivation of the species in western region of Rio Grande do Sul, carried out with seminal material, under edaphoclimatic and cultivation conditions similar to the present study, however with lower fertilizer additions (300 kg ha<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, 06:30:06 planting; 140 kg ha<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, 22:05:20 at 90 days and 22:00:18 at 270 days) (DICK *et al.*, 2016). In the referred study, the authors observed that the trees produced 58.7 Mg ha<sup>-1</sup> of total above ground biomass, however, this result was only achieved after 60 months of planting and not at 36 months.

This study confirmed the hypothesis that higher doses of fertilizer did not increase biomass production. Biomass production tends to be higher in fertilized plantations when compared to those without added nutrients (STAPE *et al.*, 2010; SILVA *et al.*, 2013); however, adding higher fertilizer doses does not necessarily imply an increase in biomass allocation, especially in stemwood.

This response is due to the variability of factors that influence biomass production, both environmental (STAPE *et al.*, 2010) and intrinsic to eucalyptus species (SILVA *et al.*, 2013). The effect of species on variations in quantities of biomass produced was observed in plantations grown in same site, which received the same fertilizer dosage, where *Eucalyptus saligna* produced more total biomass and stemwood when compared to

*Eucalyptus urograndis* (VIERA *et al.*, 2017). The genetic factor may not be a condition that explains the responses to fertilization. Both in trees originating from seminal material evaluated in this study, and in clonal plantations of *Eucalyptus* (STAPE *et al.*, 2010); there was no influence of the fertilizer dose on biomass production.

In relation to environmental factors, water availability is more determinant to increase in biomass production than fertilization, since different levels of fertilizer (14 or 724 kg ha<sup>-1</sup> of N; 14 or 284 kg ha<sup>-1</sup> of P; and 109 or 669 kg ha<sup>-1</sup> of K) did not influence the amount of biomass produced in *Eucalyptus* plantation, at 33.6 months after planting, where there was a production of 43.7 Mg ha<sup>-1</sup> of stemwood (STAPE *et al.*, 2010). This study was carried out in clonal plantations with different ages, grown in different places in Brazil, indicating in all situations that the greatest biomass production occurred when there was water availability, and not after the fertilizer increase.

Water is one of the most important factors in forest production and water availability in the soil directly influences the absorption of nutrients by trees, which may limit the use of mineral fertilizer applied to the soil, due to lack of means of transport (aqueous solution) of mineral to root (PALLARDY, 2008). However, in study site there is water availability, since rainfall was well distributed throughout the year and there was no drought period that led to a water deficit. The soil type where *Eucalyptus dunnii* trees were cultivated, dystrophic Inceptisol, presents the incipient B horizon with a higher clay content compared to superficial layer A (Table 1). This morphological soil characteristic also reduces the rate of water percolation along the profile, keeping the soil moist for a longer period of time.

Factors related to soil, such as fertility, humidity, texture, among others, can also influence the dynamics of tree biomass production. The effect of soil texture on biomass production, due to fertilization, was verified in sandy soil (more than 90% sand in textural composition), not irrigated, where *Eucalyptus grandis* was responsive to highest fertilizer doses (SILVA *et al.*, 2013). In this study, with the addition of 160, 64 and 210 kg ha<sup>-1</sup> of N, P and K, respectively, there was 4.8 Mg ha<sup>-1</sup> more biomass produced in stemwood compared to dosage of 40, 16 and 53 kg ha<sup>-1</sup> of N, P and K, respectively. Increasing the fertilizer dose also conditioned higher production of leaf and stemwood biomass in *Eucalyptus urograndis*, as long as fully weed control with herbicide (PEREIRA *et al.*, 2012).

In the trees of *Eucalyptus dunnii* and other species, stemwood represents the largest biomass proportion and distribution pattern of the other components, which is characterized by greater number of branches in detriment to stembark, was observed in young eucalyptus plantations (VIERA *et al.*, 2017; SILVA *et al.*, 2013). As the trees grow, there is natural pruning and amount of stembark will increase (VIERA *et al.*, 2013).

As it accumulates more biomass, largest quantities of carbon are stored in stemwood (Table 3). Without the fertilization effect on biomass production of *Eucalyptus dunnii* trees, consequently, there is no influence on the carbon stock, since this cellulose structural element is directly related to the amount of biomass produced (PALLARDY, 2008). Different fertilizer dosages also did not influence the carbon stock in biomass of *Eucalyptus urograndis* young plants, when cultivated in Oxisol (STAPE *et al.*, 2008).

Due to the expressive biomass production of this study site, carbon amount stored in *Eucalyptus dunnii* trees was higher than that observed in *Eucalyptus urograndis* (TURGUILHO *et al.*, 2010) and *Eucalyptus* sp. stands (GATTO *et al.*, 2011), at five and three years of age, respectively. In contrast, carbon proportion stored in stemwood biomass varies according to productivity, age and species. In *Eucalyptus dunnii* trees evaluated in this study, 45% of stemwood biomass was composed of carbon, in *Eucalyptus globulus*, at the seven age, this proportion drops to 40.4% (LOPES and ARANHA, 2006) and *Eucalyptus* sp. stand, at three age, it was only 28.6% (GATTO *et al.*, 2011).

One of the results of this study also shows that, not always using the factor 0.5 to estimate carbon in stemwood biomass reflects reality, as it may overestimate or underestimate the carbon amount stored in plantations. Based on carbon determination carried out in this study, for plantations of *Eucalyptus dunnii*, grown in dystrophic Inceptisol in central region of Rio Grande do Sul state, Pampa biome, the factor 0.45 can be applied to estimate the carbon stock in stemwood, 0.43 to estimate carbon in stembark, 0.46 for branches and 0.51 for leaves.

## Nutrients in biomass

In plantations of different eucalyptus species, at different ages and grown in most varied sites, with exception of calcium, the other nutrients are also more concentrated in leaves (VIERA *et al.*, 2013; 2017; GUIMARÃES *et al.*, 2015; LACLAU *et al.*, 2000). This trend occurs due to the mobility of nutrients and due to the increased demand for metabolic activity in leaves, nitrogen levels are higher, as it makes up structures of amino acids, proteins and nucleic acids necessary for photosynthesis and transpiration performance (PALLARDY, 2008).

The highest concentration of potassium was a pattern observed in mineral composition of stemwood in eucalyptus (VIERA *et al.*, 2013; 2017; GUIMARÃES *et al.*, 2015; DICK *et al.*, 2016; LACLAU *et al.*, 2000), as it is the main mineral constituent of meristematic exchange cells (PALLARDY, 2008). *Eucalyptus* trees that are well nourished with potassium are more resistant to drought and frost, as this mineral promotes greater water retention in biomass and greater efficiency in water use (BATTIE-LACLAU *et al.*, 2016). Therefore, mineral fertilization with potassium is of relevant importance to forest nutrition in southern region of Brazil, especially in sites with frost incidence, as in the case of the present study, and in those with a low volume of incident rainfall.

With structural functionality, the highest concentrations of calcium are in stembark and stemwood of *Eucalyptus dunnii* trees, because the cycling was reduced in leaves due to low mobility, consequently, the leaf Ca concentrations are lower in young plants, increasing as tree grows (PALLARDY, 2008). It is the leaf concentrations of Ca that affect the eucalyptus productivity and growth, for example, when they are greater than 9.5 g kg<sup>-1</sup>, there is a reduction in *Eucalyptus grandis* height (ZAKIA *et al.*, 1983).

Increasing the nutrients dose added to soil does not necessarily imply greater biomass production (Table 3) and nutrients concentration in trees components (Table 4). This is because soil factors can limit the availability of nutrients to plants, such as formation of complexes between the elements, immobilization of nutrients by the formation of compounds and/or retention in colloids, rapid vertical leaching of nutrients (especially potassium) along the soil profile, nitrogen losses due to volatilization, among other sorption phenomena in soils (BARRETO *et al.*, 2010). Another important factor that conditions the nutrients concentration in biomass are the physiological mechanisms intrinsic to the plants, which regulate the entry of quantities of minerals necessary for development, which may limit the absorption and translocation of excess nutrients to the biomass, thus restricting the “luxury consumption”, which avoids toxicity (PALLARDY, 2008). Some species are not restricted to absorption of excess nutrients (FURTINI NETO *et al.*, 1996), for example, the phosphorus consumption by the hybrid *Eucalyptus urophylla x Eucalyptus grandis* (ROCHA *et al.*, 2013). However, these relationships still lack further studies that show, more specifically, the interactions between different species of eucalyptus and macro and micronutrients.

Another factor that can also justify the lack of higher doses of fertilizer effect on nutrient concentrations is the rapid growth of eucalyptus trees. As the tree grows, fertilization effects are mitigated by nutrients dilution in biomass components, to the detriment of carbohydrates and cellulose accumulation, which are processes resulting from maturation of plant tissues (PALLARDY, 2008). This physiological response was observed in young eucalyptus clones, cultivated in sandy soil, where the leaf nutrient content increased shortly after the addition of higher fertilizer doses, but this effect was diluted over time (SILVA *et al.*, 2013).

In this study it was also observed that increasing the fertilizer dosage reduced the nutrients use efficiency, since with addition of C2, there was a greater amount of nutrients stored in biomass components, whereas, the production does not differ from C0 (Table 5). In all treatments, there are large amounts of K stored in stemwood, indicating the future need for replacement of higher doses of K via mineral fertilization, as large quantities (> 75 kg ha<sup>-1</sup>) will be removed after stemwood harvest of this *Eucalyptus dunnii* stand.

## CONCLUSIONS

- Higher fertilizer doses did not increase the biomass production, carbon stock and nutrients in components of *Eucalyptus dunnii* trees grown in dystrophic Inceptisol, in central region of Rio Grande do Sul state;
- In fertilization recommendations, the biomass production and carbon stock in stemwood does not vary, but the production of 58.8 Mg ha<sup>-1</sup> of total biomass, which accumulated 26.9 Mg ha<sup>-1</sup> of carbon, is an expressive amount for the species at 36 months age of *Eucalyptus dunnii* trees;
- Since the different fertilizer dosages did not influence the biomass production and, aiming at reducing costs and risks of environmental impacts caused by the excess of minerals application in soil, can be carried out 150 g plant<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, in 24:00:24 proportion, for *Eucalyptus dunnii* cultivation in dystrophic Inceptisol, in central region of Rio Grande do Sul state, Brazil

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