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Estimation of nutrient export in eucalypts genotypes under different harvest intensities in southern Brazil

Estimación de la exportación de nutrientes en genotipos de eucalipto bajo diferentes intensidades de cosecha en el sur de Brasil

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The study of the nutrients removed with forest harvesting is presented as an essential fator favoring the sustainable use of forest stands. The research was carried out in an experimental area in Horto Florestal Terra Dura in the municipality of Eldorado do Sul, RS, Brazil, where six *Eucalyptus* clones were planted. Based on the nutrient stock of each biomass component, the simulation of nutrient removal through biomass harvesting was calculated for three scenarios: (1) harvesting of stemwood, (2) harvesting of stemwood with stembark, and (3) harvesting of all aboveground biomass. In the first scenario, the highest amount of nutrients exported with biomass harvest occurred in the *Eucalyptus* hybrids *E. urophylla* x *E. globulus* (N, K, S, and Fe) and *E. urophylla* x *E. grandis* (Ca, B, Cu, and Zn). In the second scenario, the highest nutrient exportation occurred in *E. benthamii* (Provenance 1) (N, P, Ca, Mn, and B) and hybrid *E. urophylla* x *E. globulus* (K, S, and Fe). In the third scenario, the highest nutrient exportation occurred in *E. benthamii* (Provenance 1) (P, Ca, B, Mn, and Zn), *E. grandis* (Mg and Cu), and hybrid *E. urophylla* x *E. globulus* (N, K, S, and Fe). Harvesting of all aboveground biomass was the most aggressive scenario, showing the highest export of nutrients. However, for reducing the nutritional impact of biomass harvesting, the best scenario was the one in which only stemwood was harvested.

Keywords: Nutrient removal, *Eucalyptus* clones, Forest harvest.

RESUMEN

El estudio de los nutrientes extraídos con la cosecha forestal se presenta como un factor esencial que favorece el uso sostenible de las plantaciones forestales. La investigación se llevó a cabo en un área experimental en Horto Florestal Terra Dura en el municipio de Eldorado do Sul, RS, Brasil, donde se plantaron seis clones de eucalipto. Con base en el contenido de nutrientes de cada componente de biomasa, la simulación de la extracción de nutrientes por la recolección de biomasa se calculó para tres tratamientos: (1) cosecha de madera de tallo; (2) cosecha de madera con corteza de tallo; y (3) cosecha de toda la biomasa aérea. En el primer tratamiento, la mayor cantidad de nutrientes exportados con la cosecha de biomasa ocurrió en los híbridos de eucalipto E. urophylla x E. globulus *(N, K, S y Fe) y* E. urophylla x E. grandis *(Ca, B, Cu y Zn). En el segundo tratamiento, la mayor exportación de nutrientes se produjo en* E. benthamii *(Procedencia 1) (N, P, Ca, Mn y B) y* E. urophylla x E. globulus *híbridos (K, S y Fe). En el tercer tratamiento, la mayor exportación de nutrientes ocurrió en* E. benthamii *(Procedencia 1) (P, Ca, B, Mn y Zn),* E. grandis *(Mg y Cu) y* E. urophylla x E. globulus *híbridos (N, K, S y Fe). La recolección de toda la biomasa aérea fue el escenario más agresivo, mostrando la mayor exportación de nutrientes. Sin embargo, para reducir el impacto nutricional de la recolección de biomasa, el mejor tratamiento fue aquel en el que solo se cosechaba madera de tallo.*

Palabras clave: *eliminación de nutrientes, clones de* eucalipto*, cosecha forestal.*

Introduction

Among the numerous existing tree genera, the genus *Eucalyptus*, owing to its characteristics of fast growth, high productivity, wide species diversity, great adaptability to different climate and soil conditions, and varied applications, has gained considerable economic significance worldwide (Mora and Garcia 2000).

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Most eucalypts plantations, besides presenting high productivity, are managed in short rotations (6-8 years) (Gonçalves *et al.,* 2013), when compared with native forest species (Silva *et al.,* 1983). However, the rapid growth of planted forests in the country imposes a high demand on soil resources, mainly water and nutrients, raising questions about the support capacity and sustainability of these systems when used intensively (Bellote *et al.,* 2008).

In order to define management practices, both in forest stands and natural forests, the study of nutrients removed with forest harvesting is an essential factor favoring the sustainable use of these systems. Considering that the amount of nutrients exported from a stand by forest harvesting is determined by the proportions between the biomass components and the harvest intensity used. In this context, the maintenance of forest productivity will depend on the proportion between the nutrients that are exported and those that remain in the system, in organic and mineral forms (Viera *et al.,* 2015). To do this, prolonging the harvest cycle and adopting a harvest regime of only stemwood are important ways to reduce the export of nutrients (Wang *et al.,* 2016).

The quantification of biomass and the export of nutrients in forest stands is of fundamental importance to understand the dynamics of nutrients in various compartments of the stands, thus allowing the identification of the indicators of possible effects of some silvicultural techniques (Londero *et al.,* 2011). Therefore, the knowledge of nutrient allocation in different parts of trees allows a forester to select the harvesting techniques that reduce the exportation of nutrients from the site of harvest (Santana *et al*., 2008). In view of the above information, the present work aimed to estimate the amount of nutrients exported in *Eucalyptus* genotypes exposed to different harvest intensities in southern Brazil.

Materials And Methods

Study site

The present study was carried out in an experimental area in Horto Florestal Terra Dura owned by Celulose Riograndense - CMPC, in the municipality of Eldorado do Sul, RS, Brazil. This study area is located at the geographic coordinates of 30º11'30.3''S and 51º37'47.7''W, with an altitude of approximately 158 m.

According to the climatic classification of Köppen, the predominant climate of the study area is Cfa (humid subtropical climate), with an average temperature of 19 ºC and an average annual precipitation of 1,400 mm (Alvares *et al.* 2013).

The soil of the experimental area is of the Red-Yellow Argissol type. The Argisols comprise the soils made up of a mineral material charecterized by the presence of the textural B-horizon of low- or high-activity clay with low base saturation or allitic character (EMBRAPA, 2009). Table 1 shows the chemical attributes of the soil at a depth of 0 to 130 cm.

Table 1. Chemical atributes of the soil of the area implanted with different genotypes of *Eucalyptus*.

Depht	N	P	K	Ca	Mg	S	B	Zn
(cm)	%	mg g^{-1}		cmol$_c$ dm^{-3}		mg dm^{-3}	mg dm^{-3}	
0-30	0.10	2.00	0.14	3.25	0.85	19.35	0.40	0.50
30-60	0.09	1.60	0.14	0.85	0.50	32.50	0.65	0.50
60-90	0.08	0.95	0.15	1.00	0.80	61.70	0.50	0.25
90-100	0.06	0.65	0.14	0.95	0.90	60.90	0.30	0.30
100-130	0.04	0.60	0.12	0.90	0.90	59.00	0.30	0.30

Depht	Mn	Cu	Fe	pH	O.C	V	m	T
(cm)	mg dm^{-3}		g dm³	H_2O		%		cmol$_c$ dm^{-3}
0-30	12.50	0.75	0.10	5.00	0.88	35.00	34.00	10.30
30-60	13.00	1.20	0.10	4.25	0.77	11.00	71.00	13.95
60-90	6.50	1.15	0.10	4.40	0.66	14.50	68.50	15.25
90-100	4.50	0.95	0.10	4.60	0.42	17.00	63.50	11.95
100-130	4.50	0.65	0.10	4.65	0.22	19.50	60.50	10.00

O.C: organic carbon; V: base saturation; m = saturation by aluminum; t: Effective cation exchange capacity.

Plantation of forest stands

In April 2012, in a spacing of 3 m x 3 m, six clones of the genus *Eucalyptus* were planted: *E. benthamii* (P1); *E. benthamii* (P2); *E. saligna*; *E. dunnii*; hybrid of *E. urophylla* x *E. globulus* (*E. uroglobulus*) and hybrid of *E. urophylla* x *E. grandis* (*E. urograndis*). *E. benthamii* (P1) is a provenance originating from Guarapuava, Paraná, Brazil and *E. benthamii* (P2) is from Telemaco Borba, Paraná, Brazil.

Subsoiling was performed at a depth of 60 cm, using a subsoiler with three stems. Subsequently, a liming treatment was performed using 2 Mg ha^{-1} of limestone and 200 kg ha^{-1} of single superphosphate. As plantation fertilizers, 110 g plant^{-1} of N-P_2O_5-K_2O (06:30:06) + 0.3% Zn and 0.2% Cu were applied. For coverage fertilization, 200 kg ha^{-1} of N-P_2O_5-K_2O (12:00:20) + 0.7% B was applied, and for maintenance fertilization, 300 kg ha^{-1} of N-P_2O_5-K_2O (24:00:26) + 0.5% B was applied. At the time of data collection, the stands were 49 months old.

Biomass and nutrients

From the dendrometric information collected, three trees of medium diameter were sampled for each genotype. The selected trees were felled and separated in to following components: leaves, branches, stembark, and stemwood. The amounts of the nutrients in the *Eucalyptus* components were obtained by multiplying the dried biomass with the mean nutrient concentration (Table 2).

Estimation of nutrient removal by harvest

Simulation of nutrient removal through biomass harvesting was performed for three scenarios based on the nutrient stock of each biomass component:

- Harvest of the stemwood;
- Harvesting the stemwood with stembark;
- Harvesting of all aboveground biomass.

Results and Discussion

Exportation of nutrients by biomass harvesting

Harvesting of all aboveground biomass was the most aggressive nutrient export scenario (Table 3). In contrast, the harvesting only the stemwood showed the lowest nutrient removal from the system, regardless of the genotype. This scenario maintained the macro and micronutrients accumulated in the other biomass components, which varied from 54 to 79% of N (*E. urograndis* and *E. benthamii* (P2)); 52 to 63% of P (*E. benthamii* (P1) and *E. saligna*); 36 to 46% of K (*E. urograndis* and *E. dunnii*); 71 to 82% of Ca (*E. dunnii* and *E. benthamii* (P1)); 56 to 75% of Mg (*E. dunnii* and *E. benthamii* (P2)); 33 to 45% of S (*E. uroglobulus* and *E. benthamii* (P1)); 43 to 66% of B (*E. urograndis* and *E. uroglobulus*); 39 to 53% of Cu (*E. urograndis* and *E. dunnii*); 14 to 36% of Fe (*E. uroglobulus* and *E. benthamii* (P2)); 77 to 87% of Mn (*E. dunnii* and *E. saligna*); and 28 to 47% of Zn (*E. urograndis* and *E. dunnii*).

In a forest, the organic blanket and farm waste constitute the main form of transfer or return of mineral elements from the vegetation to the soil. Thus, the maintenance of forest productivity depends on the proportion between the nutrients that are exported and those that remain in the system, in organic and mineral forms (Drumond *et al.* 1997).

Considering the harvest of the wood with the stembark, the permanence of the nutrients in the area reduces to 44 to 55% of N (*E. urograndis* and *E. uroglobulus*); 29 to 43% of P (*E. benthamii* (P2) and *E. uroglobulus*); 19 to 26% of K (*E. benthamii* (P2) and *E. saligna*); 26 to 37% of Ca (*E. benthamii* (P2) and *E. uroglobulus*); 26 to 36% of Mg (*E. benthamii* (P2) and *E. uroglobulus*); 25 to 34% of S (*E. saligna* and *E. benthamii* (P1)); 28 to 40% of B (*E. dunnii* and *E. uroglobulus*); 27 to 37% of Cu (*E. urograndis* and *E. dunnii*); 11 to 27% of Fe (*E. uroglobulus* and *E. benthamii* (P2)); 33 to 46% of Mn (*E. saligna* and *E. uroglobulus*); and 17 to 28% of Zn (*E. benthamii* (P2) and *E. dunnii*).

According to Bellote and Silva (2004), the biomass of the bark is significantly smaller than that of the wood; however, it presents itself as an important nutrient storage site, especially of Ca. In this context, it becomes more sustainable to harvest only stemwood. According to Merino *et al.* (2005), the current practices of harvesting (stem and bark removal) result in high export rates of P, K, Ca, and Mg, especially in *Eucalyptus* plantations, because of the high productivity and low nutrient efficiency of the species of this genus.

In relation to macronutrients, it has been observed that with the exception of the third scenario (stem and canopy) in the stand of *E. dunnii*, where

Table 2. Amount of nutrients in the biomass components of different genotypes of *Eucalyptus* at 49-month-old established in Eldorado do Sul, RS, Brazil.

Genotype	Component	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		kg ha^{-1}						g ha^{-1}				
E. benthamii (P1)	Leaves	99.70	6.00	36.00	26.50	12.40	5.90	86.00	21.40	586.30	2,033.50	70.40
	Branches	13.40	2.40	23.50	39.30	12.80	2.20	43.60	26.30	362.90	2,173.40	76.20
	Stembark	44.10	4.80	48.60	129.80	30.20	2.70	115.30	26.10	265.20	4,164.70	130.70
	Stemwood	65.50	12.30	143.50	41.90	20.10	13.20	210.30	78.30	4,956.10	1,515.90	360.90
	Total	222.70	25.60	251.60	237.60	75.50	24.00	455.20	152.20	6,170.60	9,887.50	638.20
E. benthamii (P2)	Leaves	92.50	5.00	26.00	20.20	10.70	5.00	95.60	22.40	490.40	1.400.70	51.30
	Branches	7.70	1.30	14.60	14.90	6.70	1.50	26.40	14.20	228.60	835.00	47.00
	Stembark	45.60	6.00	42.30	70.40	31.80	3.00	113.20	21.90	240.50	2.452.30	113.30
	Stemwood	37.90	9.60	127.60	31.40	16.70	15.50	155.20	61.40	1,688.90	1,230.00	383.60
	Total	183.70	21.80	210.50	136.90	65.80	25.00	390.40	119.70	2,648.50	5,918.00	595.20
E. saligna	Leaves	66.50	4.00	26.70	14.90	10.00	4.00	92.50	17.60	248.40	574.90	38.60
	Branches	8.70	1.60	17.60	31.30	10.80	1.90	39.80	36.60	221.60	594.70	46.40
	Stembark	17.00	4.20	33.10	72.10	29.50	2.60	89.20	29.50	255.20	1,882.40	57.50
	Stemwood	53.60	5.90	95.70	34.50	25.90	15.10	131.20	80.00	1,993.90	466.70	309.80
	Total	145.70	15.70	173.10	152.80	76.10	23.70	352.80	163.80	2,719.10	3,518.70	452.30
E. dunnii	Leaves	66.00	3.80	18.50	19.90	10.80	3.90	59.50	19.50	309.90	941.40	46.70
	Branches	8.20	1.10	10.90	19.30	8.10	1.40	29.30	20.40	217.20	791.90	34.80
	Stembark	24.50	2.50	34.70	55.30	19.40	1.50	77.50	18.30	193.50	1,818.30	57.00
	Stemwood	41.50	4.80	74.10	38.20	30.30	10.40	150.40	51.00	1,304.20	1,070.80	155.20
	Total	140.30	12.20	138.20	132.70	68.60	17.10	316.70	109.20	2,024.80	4,622.30	293.70
E. urophylla x E. globulus	Leaves	120.00	6.40	40.80	27.30	14.00	6.60	99.40	27.60	548.80	1.457.60	67.80
	Branches	11.40	1.40	25.40	28.20	7.40	1.90	46.80	23.50	349.40	729.80	55.40
	Stembark	17.90	2.80	43.50	51.90	19.70	2.40	95.40	18.40	198.00	1,556.70	59.20
	Stemwood	88.10	7.70	154.80	42.80	17.50	22.10	125.80	103.20	6,782.90	1,018.30	328.50
	Total	237.40	18.40	264.50	150.20	58.70	33.00	367.40	172.70	7,879.00	4,762.30	511.00
E. urophylla x E. grandis	Leaves	64.30	3.70	23.40	16.30	12.10	3.90	93.60	19.80	227.10	599.40	39.10
	Branches	6.00	1.70	23.20	37.70	13.80	1.90	36.10	33.90	359.20	1,279.60	63.30
	Stembark	14.80	4.60	34.30	72.40	26.10	2.70	65.90	25.00	438.90	2,206.10	53.40
	Stemwood	73.00	7.30	143.00	46.10	22.90	14.80	259.50	122.50	2,553.30	852.30	396.40
	Total	158.00	17.20	223.90	172.50	74.90	23.40	455.00	201.10	3,578.50	4,937.40	552.10

Source: Santos *et al.* (2019).

N was the element removed in greater quantity, the other scenarios and genotypes showed the highest export of the macronutrient K. In the case of micronutrients, Fe was the element removed in greater quantity in the first scenario (harvesting of only stemwood). In the second (harvesting of stemwood and stembark) and third (harvesting of stem and canopy) scenarios, Mn was the micronutrient exported in greater quantity in all *Eucalyptus* species, except for *E. uroglobulus*, where the element removed in greater quantity was Fe. In contrast, the smallest exported micronutrient in all scenarios and genetic materials was Cu.

It is worth mentioning that in the first scenario, the highest amount of nutrients exported with biomass harvesting occurred in *E. urophylla* x *E. globulus* (N, K, S, and Fe) and *E. urophylla* x *E. grandis* (Ca, B, Cu, and Zn). In the second scenario, the highest nutrient removal occurred in *E. benthamii* (P1) (N, P, Ca, Mn, and B) and *E. urophylla* x *E. globulus*

Table 3. Nutrient export estimates for the three proposed harvest scenarios.

Genotypes	Intensidade	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		kg ha^{-1}						g ha^{-1}				
E. benthamii (P1)	1^*	65.47	12.30	143.54	41.94	20.10	13.25	210.31	78.28	4,956.14	1,515.88	360.86
	2	109.60	17.10	192.20	171.70	50.30	15.90	325.60	104.40	5,221.40	5,680.60	491.60
	3	222.70	25.56	251.61	237.58	75.51	24.02	455.19	152.16	6,170.60	9,887.51	638.16
E. benthamii (P2)	1	37.89	9.60	127.56	31.37	16.65	15.53	155.16	61.36	1,688.94	1,229.97	383.57
	2	83.48	15.57	169.90	101.73	48.42	18.49	268.36	83.21	1,929.48	3,682.31	496.92
	3	183.73	21.84	210.53	136.86	65.79	24.95	390.39	119.75	2,648.48	5,917.96	595.17
E. saligna	1	53.59	5.85	95.71	34.47	25.87	15.08	131.21	80.03	1,993.89	466.66	309.77
	2	70.60	10.00	128.80	106.60	55.30	17.70	220.50	109.60	2,249.10	2,349.10	367.30
	3	145.74	15.69	173.14	152.78	76.13	23.66	352.77	163.83	2,719.08	3,518.72	452.26
E. dunnii	1	41.51	4.78	74.08	38.20	30.26	10.36	150.38	51.04	1,304.24	1,070.80	155.23
	2	66.00	7.30	108.80	93.50	49.60	11.90	227.90	69.30	1,497.70	2,889.10	212.20
	3	140.28	12.24	138.23	132.67	68.59	17.12	316.73	109.24	2,024.84	4,622.35	293.70
E. urogphylla x *E. globulus*	1	88.07	7.68	154.82	42.76	17.55	22.13	125.75	103.17	6,782.85	1,018.28	328.53
	2	105.98	10.52	198.30	94.70	37.28	24.50	221.20	121.60	6,980.84	2,574.95	387.77
	3	237.39	18.36	264.46	150.18	58.71	33.02	367.39	172.71	7,879.01	4,762.32	511.04
E. urogphylla x *E. grandis*	1	72.98	7.28	143.01	46.15	22.93	14.84	259.47	122.46	2,553.26	852.34	396.35
	2	81.65	11.86	167.09	121.32	50.45	16.98	322.06	141.04	2,973.02	3,225.62	448.77
	3	151.93	17.21	213.70	175.29	76.33	22.86	451.77	194.75	3,559.35	5,104.62	551.15

1^* - Harvesting the stemwood; 2 - Harvesting the stemwood with stembark; 3 - Harvesting of all aboveground biomass.

(K, S, and Fe). In the third scenario, the highest nutrient exportation occurred in *E. benthamii* (P1) (P, Ca, B, Mn, and Zn), *E. urophylla* x *E. globulus* (N, K, S, and Fe), and *E. grandis* (Mg and Cu). In contrast, *E. dunnii* (P, K, S, Cu, Fe, and Zn) and *E. benthamii* (P2) (N, Ca, and Mg) had the lowest amounts of nutrients exported. In the second scenario, *E. dunnii* showed the lowest amounts of nutrients (N, P, Ca, S, Cu, Fe, and Zn) removed. The potential export of nutrients from *Eucalyptus* stands harvested may be high. However, depending on the harvest method, the nutrients from the residue can be recycled (Hernández *et al.*, 2009). According to Merino *et al.* (2005), the cost of harvesting in terms of nutrients can also be reduced by carefully selecting the planted tree species and their parts for harvesting and by reducing the intensity of the harvest.

When the wood is harvested with the bark, the export of nutrients is increased considerably, reaching 63% and 74% of Ca and 64% and 74% of Mg removed from *E. uroglobulus* and *E. benthamii* (P2), respectively. According to Viera *et al.* (2015), the availability of nutrients for future plantations in a forest site is mainly related to the harvest intensity applied. In this perspective, for the greater sustainability of forest stands, the debarking of trees should be carried out before removing their trunks; this would be an effective way to reduce nutrient export. This is because without proper silvicultural management, intensive harvesting might lead to the depletion of nutrient stocks in soils in the long term (Merino *et al.* 2005).

According to Witschoreck (2008), a part of the nutrients extracted by forest harvesting can be replenished through the application of fertilizers. However, in addition to the economic and ecological aspects of the use of fertilizers, it is difficult to quantify and assess the quality of nutrients, restricting fertilizer application, in most cases, to the triad of NPK elements.

It should be noted that forest harvesting, from the nutritional point of view, should not be carried out in many young stands because of the higher export of nutrients per unit of biomass produced. Besides, for the next rotation, sustainable production practices should be carried out to maintain the nutritional balance of the site of harvest (Viera *et al.* 2015).

Conclusions

Harvesting of all aboveground biomass was the most aggressive scenario showing the highest export of nutrients.

However, for reducing the nutritional impact of biomass harvesting, the best scenario was the one in which only stemwood was harvested.

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