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Controlled release fertilizer and container volumes in the production of *Parapiptadenia rigida* (Benth.) Brenan seedlings

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ABSTRACT. Growing demand for native tree seedlings will require improvements in quality standards of production processes through the use of more efficient cultivation techniques. This study evaluated the effects of different doses of controlled release fertilizer (CRF) and different container volumes in the production of *Parapiptadenia rigida* seedlings. We examined the effects of five different concentrations (0, 3, 6, 9 and 12 g L^{-1} substrate) of CRF (18-5-9 NPK) and three different container volumes (50, 110 and 180 cm^3) on seedling height (H) and collar diameter (CD) measured monthly for seven months and then calculated H/CD ratios. After 210 days of growth, the dry masses of the aerial portions, root systems, and total masses were determined, as well as the concentrations of macro- and micronutrients in the aerial portions of the seedlings. In general, the dose 9 g L^{-1} substrate combined with the 180 cm^3 cultivation tubes demonstrated the best results in terms of the morphological variables analyzed, resulting in consistent quality seedlings for field planting.

Keywords: native species, fertilizer, containers, nursery.

Fertilizante de liberação controlada e volume de tubetes na produção de mudas de *Parapiptadenia rigida* (Benth.) Brenan

RESUMO. A crescente demanda por mudas de espécies florestais nativas exige o aprimoramento do padrão de qualidade do processo produtivo, por meio de técnicas mais eficientes utilizadas nos viveiros. Dessa forma, este estudo teve por objetivo avaliar o efeito de diferentes doses de fertilizante de liberação controlada (FLC) e volume de tubetes na produção de mudas de *Parapiptadenia rigida* em viveiro. Foi avaliado o efeito de cinco doses (0, 3, 6, 9 e 12 g L^{-1} de substrato) de FLC, NPK (18-5-9) combinadas com três volumes de tubetes (50, 110 e 180 cm^3). Foram realizadas, mensalmente, durante sete meses, mensurações da altura (H), diâmetro do coleto (DC) e calculada a relação H/DC. Aos 210 dias foram avaliadas as massas secas da parte aérea, sistema radicular, total e determinado o teor de macro e micronutrientes na parte aérea das mudas. De maneira geral, a dose de 9 g L^{-1} de substrato combinada com o tubete de 180 cm^3 apresentou os melhores resultados para as variáveis morfológicas analisadas, obtendo-se mudas com padrão de qualidade para o plantio a campo.

Palavras-chave: espécie nativa, fertilização, recipientes, viveiro.

Introduction

The identification of the ideal chemical composition of substrates is an important step in producing high-quality tree seedlings (WENDLING et al., 2007). Substrate fertility is a critical factor in the production of healthy seedlings under nursery conditions, as rapidly exhaust nutrients stored in the seeds (JACOBS; LANDIS, 2009). The use of growing media that have adequate physical and structural characteristics but low concentrations of nutrients makes added fertilizers an important source of available nutrients for plant growth (OLIET et al., 1999).

The deficiency of a single essential mineral element can result in metabolic disturbances that will limit plant growth and development (BARKER; PILBEAM, 2007; TAIZ; ZEIGER, 2009). The total availability of nutrients can vary widely within an adequate range without any perceivable effect on dry matter yields because once the basic needs of the plant are satisfied, additional fertilization use will not result in a further growth response but will result in what is called “luxury consumption” (LARCHER, 2006).

To obtain optimal seedling responses, it is important to determine the nutritional requirements of each species, adequate production methods, and the optimal nursery growth period (VALERI; CORRADINI, 2005). Substrate fertilization is an extremely important process in the commercial production of tree seedlings because it provides seedlings with the nutritional conditions required for optimal growth (BRONDANI et al., 2008; GONÇALVES et al., 2012). The addition of a topdress-fertilizer during the growth phase of commercial seedlings is generally undertaken by applying liquid fertilizers (MORAES NETO et al., 2003a).

Another important factor during commercial seedling production is the choice of the type container-grown, as they influence the amount of water and mineral nutrients available to plants, and their characteristics and dimensions can influence many operational aspects of production processes (LUNA et al., 2009).

In the evolution of silvicultural techniques for seedlings production, various types of containers have been developed to optimize plant growth and reduce production costs. Nurseries have recently taken to using low-volume recipients due to their low costs and their ability to produce more seedlings per unit area (DOMINGUEZ-LERENA et al., 2006).

Polyethylene tubes are the main containers used for producing forest tree seedlings because of the following advantages in comparison to polyethylene bags: they stimulate the development of higher quality root systems; allow for a greater degree of mechanization and facilitate ergonometric processes during production; can be repeatedly utilized; require considerably less substrate; facilitate seedlings removal and handling; allow greater seedlings production per unit area; and reduce transportation costs (DAVIDE; FARIA, 2008; GOMES; PAIVA, 2008; GONÇALVES et al., 2005; WENDLING et al., 2001).

Investigations will be necessary to determine the most favorable techniques for producing quality seedlings of native forest species due the growing demand for these plants for a wide variety of uses. *P. rigida* (Benth.) Brenan (Fabaceae) ("angico-vermelho") is well known in southern Brazil and is used in civil construction, as an energy source (BACKES; IRGANG, 2009), and in many outdoor applications (such as wood poles) due to its highly natural wood resistance. This native species is widely used in reforestation and environmental recovery programs, but little is known about its cultivation requirements.

Therefore, to increase our knowledge of the silvicultural techniques appropriate for the cultivation of *P. rigida* for reforestation purposes, this study evaluated the effects of different controlled release fertilizer rates and different container volumes on the production of nursery seedlings.

Material and methods

This study was conducted in the forestry nursery of the Department of Forest Science at the Federal University of Santa Maria (UFSM) (29°43'S; 53°43'W) in Rio Grande do Sul State, Brazil. Seeds were collected from 28 trees of *P. rigida* growing in fragments of seasonal deciduous forests in the municipality of Santa Maria. The collected seeds were processed and subsequently stored in semi-permeable polyethylene bags in a cold chamber (T = 8°C; R.H. = 86%) for 212 days.

Fifteen different treatments were evaluated using containers with three different volumes (50 cm^3, 110 cm^3 and 180 cm^3) and five different rates of controlled release fertilizer (CRF - Osmocote® 18-5-9) (0, 3, 6, 9, and 12 g L^{-1} substrate) with four replicates of 27 plants each. The culture tubes were held in plastic racks (43.5 x 63 cm; 16.5 cm tall) that could accommodate 48 containers.

The containers were each filled with a substrate composed of a commercially available peat (Carolina Soil®) mixed with 20% (V V^{-1}) charred rice husks. This substrate had the following characteristics: pH, 6.08; electrical conductivity, 408.5 μs cm^{-1}; density, 278 kg m^{-3}; aeration space, 30.6%; and easily available water, 23.7%.

Two seeds were initially sown in each container, but after 30 days, the seedlings were thinned and staggered to hold 27 culture tubes per rack. Fertilization was initiated 90 days after sowing with weekly applications of 3 g Peter's Professional® liquid fertilizer (9-45-15 NPK) per liter of water, with 5 L applied to 1,620 seedlings.

The seedlings were maintained in a greenhouse for 180 days and subsequently transferred to an acclimatization nursery area for an additional 30 days. Irrigation in the greenhouse was performed daily using a movable bar of micro-sprinklers providing a 5 mm water layer in the greenhouse and 17 mm in the nursery. Irrigation was either suspended or reduced on rainy or cooler days, respectively.

At 90, 120, 150, 180 and 210 days after sowing, eight seedlings were randomly selected from each plot to measure the heights of their aerial portions

(H, in centimeters) and their collar diameter (CD, in millimeters). These same plants were measured at each of the five time periods. At the end of the experimental period (210 days), eight seedlings per treatment were randomly chosen to measure: dry mass of the aerial portion (DMAP), dry mass of the root system (DMRS), and total dry mass (TDM). The aerial and root systems of these plants were separated and dried at 70°C in a forced air oven until reaching a constant weight.

At 210 days, 40 seedlings per treatment (10 seedlings from each repetition) were also randomly chosen to determine the macro- and micronutrient contents of their aerial portions. To that end, the aerial portions of the plants were dried at 70°C, ground, and assayed to determine their concentrations of nitrogen (N), using the Kjeldahl method; phosphorus (P) and boron (B), using visible light spectrometry; potassium (K), using flame photometry; sulfur (S), using turbidimetry; and calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) using atomic absorption spectrophotometry, according to the methodologies described by Tedesco et al. (1995) and Miyazawa et al. (1999).

The data were submitted to analysis of variance to determine the significance of the main effects, factors, and their interactions. The means were compared using the Scott-Knott test and/or polynomial regression at a 5% significance level. In cases of significant effects of quadratic equations, the critical points (CP) or maximum technical efficiency doses (MTED) were determined. All analyses were run on Sisvar statistical software (FERREIRA, 2008).

Results and discussion

Seedling growth

The collar diameter showed significant dose x time ($p = 0.0000$) and container x time ($p = 0.0001$) interactions. The collar diameter of the seedlings increased over time, demonstrating quadratic growth as a function of fertilizer dosage at all evaluation times (Table 1). According to Table 1, the estimated maximum technical efficiency dose (MTED) for this variable varied between 8.9 and 9.9 g L^{-1} during the nursery growth period, with an average value of approximately 9.3 g L^{-1}.

Fertilization above the estimated maximum technical efficiency level reduced collar diameter, most likely due to nutrient toxicity or induced deficiencies (as competition for the same transport mechanism between ions with the same valence can inhibit nutrient uptake) (WHITE, 2012). As such, it appears that the highest CRF doses (12 g L^{-1}) inhibited the absorption of certain nutrients due to the high concentrations of mineral salts in the substrate. Seedlings exposed to 9.0 g L^{-1} fertilizer doses demonstrated 28% increases (3.1 mm) in their collar diameters over controls at 210 days.

In analyzing the effects of different container sizes on collar diameter over time, no significant differences could be observed until 150 days after sowing (Table 2). At 180 days, the collar diameter of the seedlings grown in 50 or 110 cm^3 containers were similar, whereas the 180 cm^3 containers produced seedlings with larger collar diameter. At 210 days, the smallest collar diameter was observed in seedlings grown in the 50 cm^3 containers (most likely due to space limitations imposed on their root systems). Independent of the culture tubes used, all seedlings attained collar diameter greater than 3 mm at the end of the study period - a measurement considered a standard for commercial forest tree seedlings (GOMES; PAIVA, 2008). Collar diameter are directly related to the development of seedling root systems, and seedlings grown in the 180 cm^3 containers can have rapid establishment and initial development on the outplanting site.

Table 1. Regression equations and the estimated maximum technical efficiency dose (MTED) in collar diameter (CD) and height (H) of *P.. rigida* seedlings at different evaluation times.

Variable	Time (days)	Regression equation	R^2	MTDE (g L^{-1})
Collar diameter (mm)	90	$y = -0.0024x^2 + 0.0472x + 0.9406$	0.9485	9.9
	120	$y = -0.0076x^2 + 0,1354x + 1,0766$	0.9626	8.9
	150	$y = -0.0122x^2 + 0.2272x + 1.1662$	0.9623	9.3
	180	$y = -0.0222x^2 + 0.4144x + 1.2466$	0.9607	9.3
	210	$y = -0.0353x^2 + 0.654x + 1.2686$	0.977	9.3
Height (cm)	90	$y = -0.0284x^2 + 0.575x + 3.3374$	0.9679	10.1
	120	$y = -0.0792x^2 + 1.5736x + 3.8303$	0.9484	9.9
	150	$y = -0.1484x^2 + 2.9569x + 4.1204$	0.9744	10
	180	$y = -0.2697x^2 + 5.3186x + 4.0226$	0.985	9.9
	210	$y = -0.3122x^2 + 6.4862x + 3.5245$	0.9942	10.4

Table 2. Effects of different containers volumes on the collar diameter (CD) and height (H) of *P. rigida* seedlings over time.

Container (cm^3)	Time (days)				
	90	120	150	180	210
	Collar diameter (mm)				
50	1.09 a*	1.47 a	1.84 a	2.47 b	3.18 c
110	1.09 a	1.48 a	1.87 a	2.49 b	3.27 b
180	1.10 a	1.48 a	1.90 a	2.63 a	3.41 a
	Height (cm)				
50	5.03 a	8.60 a	12.84 c	18.55 c	20.85 c
110	5.23 a	8.95 a	13.77 b	20.74 b	25.49 b
180	5.49 a	9.44 a	14.94 a	24.83 a	30.41 a

*Means of each variable not followed by the same letter in a given column differ by the Scott-Knott test at a 5% level of probability.

A number of studies with forest species have demonstrated effects of container volumes on seedling growth. Brachtvogel and Malavasi (2010) observed that *P. dubium* seedlings demonstrated high average collar diameter with added conventional fertilization (per m^3 of substrate) or with individual fertilization (in each recipient) when grown in larger-dimension container. Ferraz and Engel (2011) evaluated the effects of different size containers on the quality of seedlings and noted that *P. rigida* seedlings produced in 300 cm^3 containers had larger collar diameter than those produced in 50 and 110 cm^3 containers and, at the end of the final evaluation period (170 days), these seedlings had collar diameters of 6.09 mm in the larger recipient but only 4.58 mm in the two smaller container.

In relation to seedling heights, significant interactions were observed (p = 0.0000) between the factors CRF dose x container volume x time, although analyses of the response surface did not indicate an absolute maximum point (the combination of CRF dose and time that resulted in the greatest height for each tube volume). As such, analyses of paired interactions were undertaken. Analyses of the dose x container interactions (Figure 1) indicated that the seedlings of *P. rigida* with greatest average heights were cultivated in the largest container volume at all CRF doses, with less growth in the smallest containers. The seedlings grown in the 50 and 110 cm^3 containers were only had similar responses at CRF dose of 12 g L^{-1}. All of the containers demonstrated quadratic growth behavior in terms of fertilization doses, corroborating the results observed for collar diameter.

The optimal CRF dose estimated by the maximum efficiency technique for the 180 cm^3 containers was 9.3 g L^{-1}, whereas the estimated doses for the other containers were larger, indicating a tendency towards uniform increases in MTED with smaller volume containers (Figure 1). This result is most likely due to smaller quantities of substrate in the smaller containers that limit root growth, as well as the reduced amounts of nutritional reserves available to the plants in smaller volumes; the seedlings will therefore need larger quantities of fertilizer - up to a certain limit - to compensate for leaching losses and greater demands during their growth phase. During the rapid growth phase both the concentrations and ratios of nutrients in smaller growth volumes can change rapidly, requiring greater attention by silviculturists to ensure constant replacements of certain nutrients and a balance in terms of essential mineral requirements (LANDIS, 1989). Studies with *E. grandis* (GOMES et al., 2003), *C. japonica* (SANTOS et al., 2000), and *P. dubium* have shown that decreasing the volume of the growth recipient will restrict root system growth and causing smaller seedlings, depending on planting densities (BRACHTVOGEL; MALAVASI, 2010).

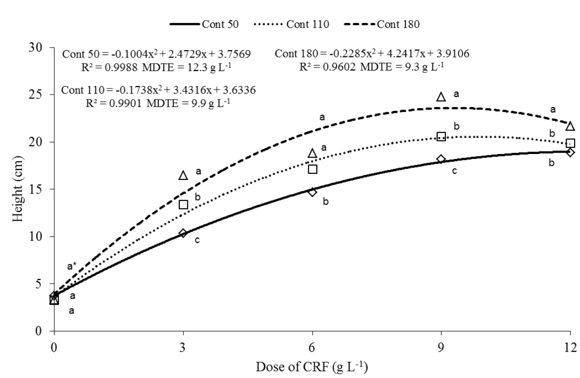

Figure 1. Height increases of *P. rigida* seedlings grown in different containers volumes (50, 110, and 180 cm^3) as a function of controlled release fertilizer (CRF) doses. *Means not followed by the same letter for each CRF dose differ by the Scott-Knott test at a 5% probability level.

Evaluations of the interaction of dose x time in terms of seedling height, as seen in Table 1, indicated that the seedlings demonstrated quadratic growth at all evaluation times and that growth in height increased over time (with the exception of the no fertilizer seedling which these variations were less pronounced) with a final value of 3.46 cm. This behavior was similar to that observed with collar diameter, although nutritional requirements were greater for the aerial portions of the seedlings.

As seen in Table 1, the doses of the estimated maximum efficiency technique for height varied between 9.9 and 10.4 g L^{-1} over time, corresponding in general to a value of 10.1 g L^{-1}. Similar to the observed results for collar diameter, seedling height decreased with fertilizer concentrations greater than 9.0 g L^{-1}, except for seedlings produced in the smallest containers (which demonstrated increased growth with increased fertilizer application) (Figure 1). At 180 days after sowing, the seedlings attained heights of 30.9 cm with 9.0 g L^{-1} fertilizer dose.

The container x time interactions indicated (Table 2) that container volumes did not restrict the height growth of the seedlings up to 120 days after sowing. After this period, however, the 180 cm^3 containers produced taller plants, followed by the intermediate tubes, whereas the smallest containers significantly limited seedling growth, yielding shorter heights up until day 210.

At the end of the greenhouse phase, the seedlings showed heights of 20.8 cm (50 cm^3), 25.5 cm (110 cm^3), and 30.4 cm (180 cm^3 containers). Davide and Faria (2008) reported that larger containers (such as 180 cm^3) had the advantage of allowing longer nursery permanence time for the seedlings before outplanting and containers of 50 cm^3 are more indicated for pioneer species.

The height of the aerial portions of seedlings is not considered very informative when analyzed separately, as this parameter allows only an approximate evaluation of the photosynthetic capacity and transpiration area of the plant because it does not consider stem architecture (BIRCHLER et al., 1998; RITCHIE et al., 2010). Taller seedlings have the advantage of being able to compete more successfully with weeds, and their sizes may indicate higher genetic; however, plants with larger transpirational areas can suffer more from water stress, mainly before the full establishment of their root systems after transplanting (HAASE, 2008).

Analyses of dry mass values (DMAP, DMRS and TDM) at 210 days indicated interactions between the factors dose x container ($p = 0.0387$) only for DMRS; the other variables demonstrated only isolated interactions between fertilizer doses and container sizes. Quadratic growth responses were observed for the dry mass, estimated by MTED at 9.82 g L^{-1} for DMAP, and 9.41 g L^{-1} for TDM (Figure 2A). Higher fertilizer doses than these resulted in reduced growth; it was not possible to evaluate the fertilizer control plants due to insufficient material for testing.

The interactions of dose x container showed quadratic growth of seedlings cultivated in containers with different volumes in terms of DMRS, so that the MTED corresponded to 10.14 (50 cm^3), 8.01 (110 cm^3), and 7.41 g L^{-1} (180 cm^3 containers), as seen in Figure 2B. The 180 cm^3 containers demonstrated greater DMRS values at all doses tested, although there were no significant differences between the 9 and 12 g L^{-1} doses in the different containers. Seedlings grown in the smaller tubes, however, showed more significant responses to increases in DMRS with increasing fertilizer concentrations.

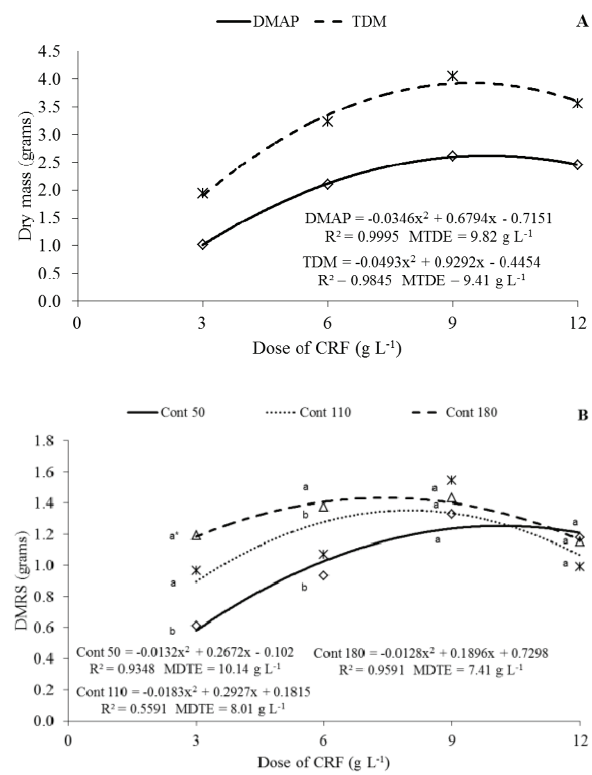

Figure 2. (A) Responses of dry mass of the aerial portion (DMAP), total dry mass (TDM), and (B) dry mass of the root systems (DMRS) of *P. rigida* seedlings grown in 50, 110, and 180 cm^3 containers as a function of CRF doses at 210 days. *Means not followed by the same letter in each CRF dose differ by the Scott-Knott test at a 5% probability level.

Figure 3 shows that DMAP, DMRS, and TDM values were larger in the 180 cm^3 containers, with no significant differences between the DMRS values of the 50 and 110 cm^3 containers. Other authors likewise noted that reductions in recipient volumes resulted in reductions in the dry masses of the tree seedlings, as was reported for *C. japonica* (SANTOS et al., 2000), *E. grandis* (GOMES et al., 2003), *S. terebinthifolius* (JOSÉ et al., 2005), *C. trichotoma*, *J. micrantha* (MALAVASI; MALAVASI, 2006), and *P. dubium* (BRACHTVOGEL; MALAVASI, 2010).

According to Haase (2008), seedlings with the highest root biomass tended to grow more and survive better than plants with lower root biomass and had strict correlations between root dry mass and the height aerial portion. The dry mass of the aerial portion of the seedling may be indicative of their resilience (GOMES; PAIVA, 2008).

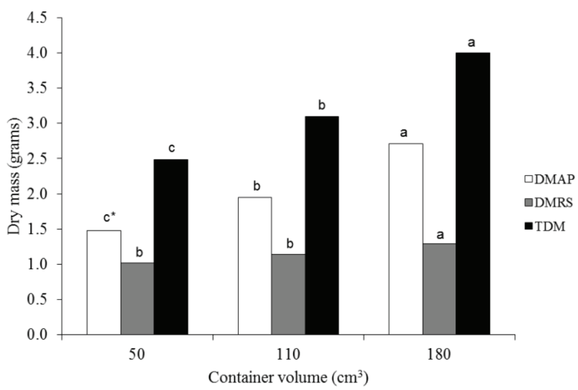

Figure 3. Dry mass of the aerial portions (DMAP), dry mass of the root system (DMRS), and total dry mass (TDM) of *P. rigida* seedlings produced in 50, 110, and 180 cm^3 containers at 210 days. *Means not followed by the same letter in each container size category differ by the Scott-Knott test at a 5% level of probability.

Considering 25 cm height and 3 mm collar diameter as minimum values for standard seedlings for field planting (DAVIDE; FARIA, 2008), seedlings grown in 110 and 180 cm^3 containers attained these values in approximately 210 days of cultivation under nursery conditions, whereas seedlings cultivated in 50 cm^3 containers did not attained ideal heights even at the highest fertilization levels, thus requiring more nursery time.

Nutrient contents

Analyses of variance indicated that the concentrations of the elements P, K, Mg, S, Fe, Mn, and Zn varied significantly in the aerial portions of the seedlings in response to interactions between CRF doses x containers at 210 days after sowing. The N and B concentrations in plants demonstrated significant differences between fertilizer doses and the different container sizes, but Ca and Cu only demonstrated fertilizer effects (Table 3). Higher levels of macro- and micronutrients were observed in the aerial portions of *P. rigida* seedlings in the 180 cm^3 containers at all CRF doses. In general, it can be observed that in terms of the mineral salts that demonstrated interactions between doses and tubes, the control (without fertilizer) and the 12 g L^{-1} CRF dose, resulted in the greatest concentration of nutrients in the aerial portions of the seedlings for the three container volumes evaluated. The lowest concentration of nutrients in the aerial portions of the seedlings were observed in the 3, 6 and 9 g L^{-1} treatments.

The nitrogen content of the seedlings increased as higher quantities of CRF were provided, however the control seedlings had the lowest values. Seedlings cultivated in the 180 cm^3 containers demonstrated the highest concentrations of nitrogen, whereas those cultivated in the 50 cm^3 containers had the lowest (Table 3). Seedlings grown in the largest recipients with the highest doses of fertilizer had leaves that were much darker green and had more abundant aerial portions compared with control plants (without fertilizer, which were small and had yellowish leaves).

Although seedlings exposed to the highest CRF concentration used (12 g L^{-1}) had the highest nitrogen content, no positive effect on seedling growth was observed in the greenhouse phase as, in general, doses greater than 9 g L^{-1} caused decreases in most of the morphological variables analyzed (due to the toxic effects of excess nutrients, including nitrogen).

The seedlings cultivated in the 180 cm^3 containers had P, K, Mg, and S contents that were significantly greater than those observed in the control plants. As CRF doses increased to 6 and 9 g L^{-1}, the nutrient concentrations in the aerial portions of the plants grown in 180 cm^3 containers decreased; nutrient contents were observed to increase at CRF concentrations above 9 g L^{-1}, although generally at levels below those of the control plants (without CRF).

All of the treatments evaluated in the present study resulted in nutritional contents in the seedlings that were significantly lower than those reported by Silveira et al. (2001) for *E. grandis* (Table 3), which was most likely due to the increased porosity of the substrate caused by the presence of charred rice hulls that allowed greater leaching.

Analyses of the concentrations of micronutrients in the aerial portions of the seedlings indicated that no influence was observed by the size of the recipient, only by fertilization. The greatest fertilizer dose combined with the largest tubes (180 cm^3) resulted in the highest concentrations of micronutrients in seedlings. Boron could not be analyzed in the fertilizer control sample as insufficient material was available for testing.

Table 3. Nutrient mineral concentrations in the aerial portions (stem + leaves) of *P. rigida* seedlings grown in different concentrations of controlled release fertilizer (CRF) and in different containers volume after 210 days of cultivation.

		Macronutrients (g kg^{-1})						Micronutrients (mg kg^{-1})				
Dose of CRF (g L^{-1})	Tube (cm^3)	N[1]	P	K	Ca[1]	Mg	S	B[1]	Cu[1]	Fe	Mn	Zn
	50	10.94 a*	2.31 Ab	8.13 Aa	12.12 a	5.87 Aa	1.77 Ab	24.56	4.60 a	35.04 Ab	55.86 Ab	28.22 Aa
0	110	10.91 a	2.40 Ab	9.15 Aa	13.24 a	5.94 Aa	2.14 Aa	N.S	4.98 a	27.19 Bb	72.56 Aa	26.96 Aa
	180	12.75 a	2.65 Aa	7.25 Ba	11.58 a	5.01 Ab	2.34 Aa	22.71	4.49 a	50.72 Ba	74.23 Ba	26.53 Ba
	50	9.93 b	1.59 Ba	5.80 Ba	7.47 a	3.48 Bb	0.60 Bb	17.78 a	2.14 a	46.50 Ab	16.71 Cb	13.75 Ba
3	110	12.08 b	1.52 Ca	6.23 Ba	7.31 a	3.14 Bb	0.66 Bb	18.76 a	2.18 a	45.76 Ab	25.50 Cb	14.22 Ca
	180	16.54 a	1.62 Ba	7.70 Ba	8.54 a	4.56 Aa	0.95 Ca	20.28 a	2.15 a	66.17 Ba	36.23 Ca	16.59 Ca
	50	11.77 b	1.35 Cb	6.25 Bb	6.77 b	3.05 Bb	0.70 Bb	15.73 a	2.21 a	43.19 Ab	35.83 Bc	14.98 Bc
6	110	15.25 b	1.45 Cb	7.25 Bb	6.67 b	2.93 Bb	0.78 Bb	14.50 a	2.64 a	48.24 Ab	49.60 Bb	18.77 Bb
	180	19.21 a	1.73 Ba	9.43 Aa	8.22 a	4.32 Aa	1.17 Ca	17.33 a	2.74 a	79.67 Aa	69.17 Ba	25.35 Ba
	50	14.14 b	1.36 Ca	6.38 Ba	4.66 a	2.57 Ba	0.78 Bb	14.21 a	2.60 a	49.03 Aa	39.28 Bb	16.72 Bb
9	110	14.32 b	1.53 Ca	6.90 Ba	5.28 a	2.51 Ba	0.96 Ba	13.63 a	2.68 a	57.58 Aa	53.30 Ba	18.83 Bb
	180	20.25 a	1.64 Ba	8.00 Ba	5.08 a	2.70 Ba	1.12 Ca	16.53 a	2.98 a	58.26 Ba	60.90 Ba	29.71 Aa
	50	18.05 c	1.66 Bc	7.45 Ab	4.59 a	2.83 Bc	0.75 Bb	14.28 b	2.60 a	38.68 Ab	52.58 Ac	17.06 Bc
12	110	23.95 b	1.99 Bb	8.93 Aa	4.68 a	3.51 Bb	0.93 Bb	16.60 b	2.93 a	47.41 Ab	78.96 Ab	24.39 Ab
	180	30.67 a	2.72 Aa	9.65 Aa	5.49 a	4.65 Aa	1.69 Ba	22.37 a	3.05 a	62.75 Ba	101.08 Aa	32.22 Aa
C.V. (%)		18.36	9.25	15.84	13.21	12.15	15.34	14.59	14.36	16.81	15.22	10.54

*Means that are not followed by the same uppercase letter comparing each tube among the doses and in lowercase letters comparing each dose among the tubes differ significantly by the Scott-Knott test at a 5% probability level. [1] Interactions between CRF doses and containers sizes are not significant. N.S. = no sample (samples insufficient for analysis). Note: Nutrient concentrations considered adequate for 80 to 100 day-old *E. grandis* seedling leaves: Macronutrients (g kg^{-1}): N (13-15), P (1.5-2.0), K (15-20), Ca (8-12), Mg (3.0-3.5) and S (1.3-1.5). Micronutrients (mg kg^{-1}): B (30-40), Cu (10-15), Fe (80-130), Mn (300-500) and Zn (30-40). Source: Silveira et al. (2001).

In cases had interactions between factors and significant differences among the containers, it was observed that seedlings grown in 180 cm^3 containers had higher mineral nutrient contents than plants grown in smaller recipients. In terms of the CRF doses applied, the control dose demonstrated the highest levels of the nutritional elements in the aerial portions of seedlings (P, K, Ca, Mg, S, Cu and Zn), with some exceptions (Fe), followed by the 12 g L^{-1} dose (N, K and Mn).

Other studies that evaluated different techniques for fertilizing forest seedlings also reported that the nutrient contents of the aerial portions of those plants were higher in treatments without any added fertilizer (control) (MORAES NETO et al., 2003a and b; OLIET et al., 1999).

Malavolta et al. (1997) noted that there were a number of external and internal factors that could modify the rate of mineral nutrient absorption by plants. In the case mentioned above, the internal ionic state of the plants may have influenced mineral absorption. The same authors reported that roots have only a limited capacity to absorb any given element and that plants with nutritional deficiencies may accumulate more mineral nutrients than plants well-supplied with those elements.

Plants saturated with ions will absorb less ions than other plants with a low internal ion content, as the former has attained the maximum limit of absorption of a given nutrient. As such, plants with nutritional deficiencies will have greater absorption rates than plants with better nutritional condition, although if those deficiencies are highly accentuated, absorption rates will decrease due to irreversible metabolic damage (MALAVOLTA et al., 1997; PRADO, 2008). In our case, accentuated nutritional deficits were observed in the control plants.

The nutritional concentrations of *P. rigida* seedlings produced using 9 g L^{-1} CRF in 180 cm^3 tubes after 210 days of growth under nursery conditions observed the following order: N>K>Ca>Mg>P>S (macronutrients) and Mn>Fe>Zn>B>Cu (micronutrients). As such, only the N levels in *P. rigida* were higher than the nutrient levels considered adequate for 80-100 day-old *Eucalyptus grandis* seedlings (SILVEIRA et al. 2001). The concentrations of P and Zn were within the range considered adequate, whereas the other elements (K, Ca, Mg, S, B, Cu, Fe and Mn) were present in lower than recommended concentrations (Table 3).

Under those same treatment conditions (9 g L^{-1} CRF and 180 cm^3 containers), macronutrients showed the following concentrations (Table 3): N (20.25), P (1.64), K (8.00), Ca (5.08), Mg (2.70) and S (1.12 g kg^{-1}), whereas the values for the micronutrients were B (16.53), Cu (2.98), Fe (58.26), Mn (60.90), and Zn (29.71 mg kg $^{-1}$). These results corresponded to the best growth rates of *P. rigida* seedlings under nursery conditions (considering their morphological characteristics), whereas higher nutrient concentration values demonstrated negative effects on seedling growth; it was not possible to determine which elements were present in excess and were causing toxicity.

Conclusion

The application of controlled release fertilizer (CRF) in the nursery production of *P. rigida* seedlings had positive effects on plant growth, producing quality seedlings consistent with commercial field planting requirements at 180 days, thus reducing seedling production time by up to 30 days.

Dose of 9.0 g L^{-1} CRF (18-5-9 NPK) applied to a substrate composed of peat with 20% charred rice hulls in 180 cm^3 containers resulted in seedlings with superior morphological characteristics.

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