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Seedling Morphological Characteristics on Survival, Uniformity, and Growth during a Full Short Rotation in *Eucalyptus grandis x E. urophylla* Plantation

Gabriela Gonçalves Moreira [1,*], Rodrigo Hakamada [2], Renato Meulman Leite da Silva [3], Cristiane Camargo Zani de Lemos [4], Antônio Leite Florentino [5] and José Leonardo de Moraes Gonçalves [1]

1 Department of Forest Sciences, University of Sao Paulo, Piracicaba 05508-220, Brazil; jlmgonca@usp.br
2 Department of Forest Science, Federal Rural University of Pernambuco, Recife 52171-900, Brazil; rodrigo.hakamada@ufrpe.br
3 Department of Planning, Sylvamo, Mogi Guaçu 13840-970, Brazil; renato.meulman@sylvamo.com
4 Department of Management, Agriflora, Araraquara 14800-670, Brazil; kika_zani@yahoo.com.br
5 Center for Nuclear Energy in Agriculture (CENA), University of Sao Paulo, Piracicaba 05508-220, Brazil; antonio.florentinobr@gmail.com
* Correspondence: gabriela.goncalves.moreira@gmail.com

Abstract: The objective of this work was to evaluate the losses in the process, survival, uniformity and growth during an entire short rotation of a clonal planting of *Eucalyptus grandis x Eucalyptus urophylla* in Brazil as a function of the different morphological characteristics of the seedlings considered a proxy of seedling quality. Seedlings were classified in descending order of quality by the following treatments: A > B > C. Treatment D was composed of prime seedlings 180 days old in the nursery. Treatment A and B experienced a mortality rate of 3% 30 days after planting, while seedlings C and D showed a mortality rate of 8%. Throughout the entire planting process, treatment C had the highest total losses of 24%, which was 15% higher than the average of the other three treatments. The quality of seedlings, as determined by the IQD, positively correlated with stem diameter, leaf biomass, and PH50 at 60 days of age. However, these relationships lost significance at later ages, and the DQI could not explain the variation in volume and stand uniformity (PV50) along the rotation. Despite early differences, from 36 to 64 months, only old seedlings (Treat. D) showed a difference in wood volume to the other treatments.

Keywords: initial growth; uniformity; seedling quality

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1. Introduction

The global production of wood products has experienced a steady growth rate of 1% over the past five years [1]. This trend has necessitated an expansion of the cultivated area, which has increased at an average rate of 2.4% during the same period in Brazil [2].

With the rising demand for wood, foresters are actively seeking methods to enhance productivity. Notably, significant improvements in silviculture have led to a remarkable increase in productivity within Brazilian *Eucalyptus* plantations, specifically from 25 to 40 m^3 ha^{-1} yr^{-1} since the implementation of clonal plantations, attributed to genetic and silvicultural advancements [3,4].

Silvicultural practices play a pivotal role in promoting improved survival rates, uniformity, and growth of forest stands [3,5,6]. These practices encompass various operations such as soil preparation, fertilization, and planting, which provide vital resources for optimal tree growth and enable the expression of the full potential productivity of genetic material [7,8].

One crucial aspect that forest managers must address during the planting process is the selection of seedlings with characteristics that enhance survival and initial growth. Inadequate seedlings can lead to increased mortality rates and hindered initial growth [9,10], consequently necessitating post-transplantation irrigation [11]. The root system stands out as a prominent concern when studying seedling quality and survival upon field planting [12]. Several studies have correlated root deformations resulting from the use of small containers for seedling production [13,14]. The composition of the substrate also significantly impacts the morphological parameters and quality of seedlings [13,15,16]. Morphological parameters of *Eucalyptus grandis* seedlings, such as height, diameter, and dry mass of roots, stems, and leaves, are influenced by substrate quality and applied irrigation depths [17]. Different compositions of the seedling substrate affect both the area and collar diameter of six species of *Eucalyptus* and *Corymbia*, with the addition of coconut fiber organic residue, for instance, yielding seedlings of superior quality [18]. In the case of clonal seedling production, the rooting of cuttings is a crucial process influenced by various factors, such as the collection time, which significantly impacts the rooting ability of *Eucalyptus* cuttings [19]. Furthermore, the application of growth hormones, including indole butyric acid, can enhance rooting and increase the mass of aerial and root parts of the plant [20].

The assessment of plant quality encompasses the evaluation of morphological attributes (observable and measurable physical characteristics), physiological and chemical factors (internal mechanisms governing plant activity), and performance indicators (such as vigor) that provide insights into plant behavior under specific conditions and tests [21]. Additionally, the quality of the root system, including its capacity to generate new, healthy, and robust roots, plays a critical role. Numerous studies have utilized the Dickson quality index, proposed for white spruce and white pine seedlings over 60 years ago [22], as a standard evaluation of seedling quality, which has been widely adopted in forestry and agricultural sciences globally [23]. However, its applicability across different plant species and cultures requires further investigation, particularly regarding its relationship with field performance, which represents the ultimate objective of ensuring adequate seedlings.

Even clonal seedlings do not exhibit uniform growth in the nursery, necessitating one or two selection steps in many cases to group seedlings with distinct morphological characteristics [24]. However, in large-scale plantations, it is common to have seedlings with different ages and characteristics within the same stand, including variations in leaf and root systems. Operationally, it often becomes necessary to plant seedlings with different characteristics, even if they do not meet recommended quality standards or old seedlings that stays in the nursery longer than planning because of operational problems [25]. Numerous recent studies worldwide have investigated the effect of different seedling qualities on field performance [15,26–28]. However, few studies have evaluated the impact of seedling quality throughout the entire short rotation period. Moreover, there is limited research examining the relationship between morphological characteristics and operational aspects, such as the use of seedlings throughout the production process, transportation, and planting.

The objective of this study was to evaluate the losses incurred during the process, the uniformity of the stand, and growth from 30 days to 64 months in a *Eucalyptus grandis x Eucalyptus urophylla* plantation, based on different morphological characteristics of the seedlings. Four types of seedlings with distinct morphological characteristics were tested, including one considered prime quality, two under prime quality, and one old seedling that remained in the nursery for 100 days longer than the ideal period. We hypothesize that prime quality seedlings will experience fewer losses throughout the entire process, from handling and transportation to outplanting activities. A second hypothesis suggests that prime quality seedlings will exhibit higher survival rates, uniformity, and growth from the beginning to the end of the rotation period. Finally, we anticipate that seedling quality, as determined by the Dickson quality index in our case, will be associated with growth during the entire rotation period.

2. Materials and Methods

2.1. Site Description

The experiment was conducted in Guatapará, São Paulo state, Brazil (21°17′ S and 41°01′ W, 510 m altitude). The region has Aw climate [29], with a minimum annual temperature of 16 °C and a maximum of 30 °C, with an average rainfall of 1180 mm yr^{-1}. Before the installation of the experiment, the site was cultivated for 24 years with *Eucalyptus* spp. plantations, totaling four cycles of rotation, in which a production of 35 m^3 ha^{-1} yr^{-1} wood was obtained in the last rotation. The soil was classified as Red Oxisol, with a sandy loam textural class (22% clay, 68% sand and 10% loam). In the chemical characterization of this soil, the pH was 4.3 ($CaCl_2$), with 0.2 $mmol_c$ dm^{-3} of K^+, 13.0 $mmol_c$ dm^{-3} of Ca^{+2}, 2.2 $mmol_c$ dm^{-3} of Mg^{+2} (exchangeable bases) and 2.5 g kg^{-1} of organic matter.

2.2. Experimental Design

A randomized block design was carried out with four treatments and four repetitions, with a total of 16 plots. In our study, treatment refers to the morphological condition of seedlings, as it was applied by Pezzuti and Caldato (2011) [30] and Trazzi et al. (2020) [31]. The plots were represented by 81 plants (9 rows × 9 plants), with a useful area containing 25 plants in the central region of the plots (5 rows × 5 plants). Plant spacing was 3.0 × 2.5 m. The treatments were defined by morphological parameters of the seedlings, using the variables of age, height, stem diameter and stem lignification (Table 1). Treatments A, B and C were characterized by 100-day-old *Eucalyptus grandis x E. urophylla* clonal seedlings with differences in stem diameter, height and stem lignification. For these same parameters, the seedlings were classified in descending order by the following sequence: A > B > C. Quality D seedlings were characterized by being over 180 days old in the nursery (Figure 1).

Table 1. Description of seedling morphological characteristics.

Parameter	Classification According to Seedling Morphological Characteristics (Treatments)			
	A	B	C	D
Age (days)	100	100	100	180
Diameter (mm)	2.5–4.5	2.0–3.0	1.5–2.5	>3.2
Height (cm)	25–45	17–30	13–25	35–55
Height of stem lignification (cm)	6–10	3–5	<3	>10

The seedlings were produced from clonal mini garden cuttings with approximately three years of production, with transplanting in 50 cm^3 tubes filled with fertilized substrate. These seedlings remained in the greenhouse for 30 days and were transferred to the shade house after that period, where they remained for another seven days. Then, the seedlings were directed to the growing area with full light exposure, where they remained until the expedition phase for planting under field conditions. When seedlings were 100 days old, after all the processes described, we divided then into three treatments (A, B and C) that are common in this step for *Eucalyptus* seedlings accordingly morphological characteristics described in Table 1. The seedlings classified as treatment "D" underwent the same process described above; however, they stayed in the growing area for an further 100 days, simulating seedlings that stay for a higher time in the nursery because of operational issues, such as planting delay or transportation schedules.

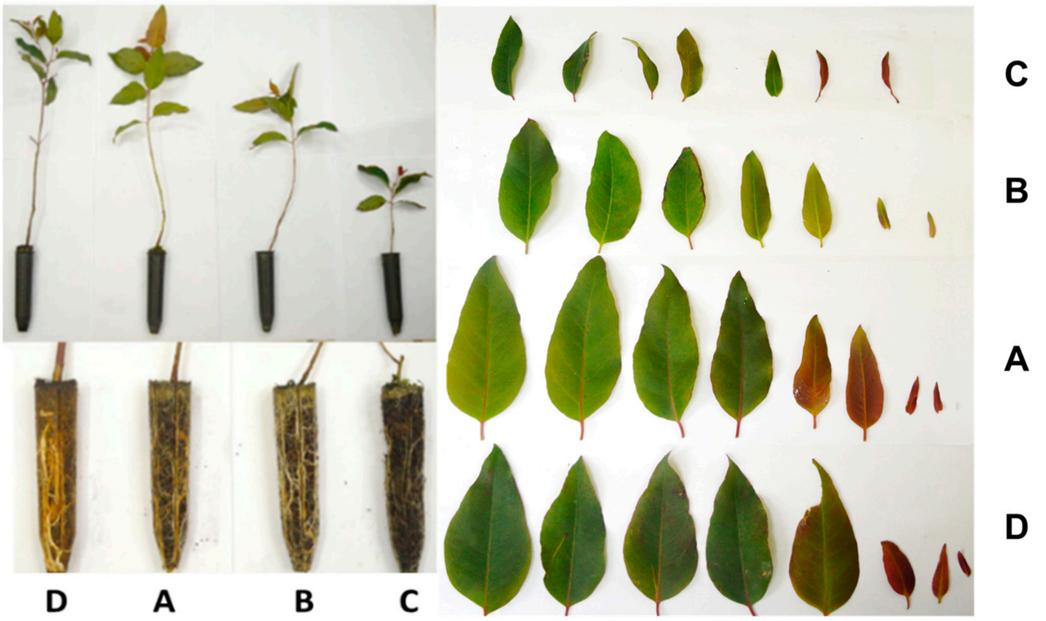

Figure 1. Visual aspects representing the morphological characteristics of an average seedling under each treatment, with seedling (**A**) being the prime seedling, seedlings (**B**,**C**) under prime and (**D**) considered as old seedlings that stayed approximately 180 days in the nursery (against 100 days of the others).

Before installing the experiment, the soil was prepared with a forest subsoiler at a depth of 0.6 m. The seedlings were immersed in a solution with Imidacloprid at 1% v/v for phytosanitary control of termite attack. All spots where seedlings died were replanted after the 30 days evaluation. The first fertilization of the plants was in a lateral trough 0.15 m away from the collar of the plants and 0.2 m deep, which consisted of the application of 22, 86, 29, 0.5, and 1.0 kg ha^{-1} of N, P_2O_5, K_2O, Zn and Cu, respectively. At four and twelve months of age, topdressing fertilization was carried out in the form of a continuous fillet between the planting lines and in the projection of the tree crowns. At four months after planting, the first cover fertilization was applied in the amount of 34, 84 and 2.9 kg ha^{-1} of N, K_2O and B, respectively. At twelve months of age, the second cover fertilization was carried out, with values of 97 and 1.8 kg ha^{-1} of K_2O and B, respectively.

2.3. Evaluations

Mortality, Seedling Losses during the Process and Wood Growth

The seedling mortality rate was evaluated 30 days after planting in 49 plants in each plot. We also tracked the seedling losses of each treatment during the whole silvicultural process, from transportation to the losses during planting, including the process of taking seedlings out of the seedling pots. In the 25 useful plants of each plot, the collar diameter (DC) and plant height (H) were measured at 60, 90 and 120 days after implantation. At 12, 24, 36 and 48 months of age, the diameter at breast height (DBH) and the height (H) of trees were measured. With the DBH and height values, the individual volume was estimated from Equation (1) [32].

$$ln(V) = -10.0495 + 1.8635ln(DBH) + 1.0436(H) \quad (1)$$

where

ln: neperian logarithim,
V: individual volume,
DBH: diameter at breast height (1.3 m above soil level), and
H: height.

Leaf Area and Biomass

The dry mass of stem, root and leaves was determined at 60, 90 and 120 days of age in four plants per treatment. Two of them represent the medium plant, having a medium height and a medium stem diameter; one seedling had the mean height plus the standard deviation and the mean collar diameter plus the standard deviation; and the latter had the mean height minus the standard deviation and the mean neck diameter minus the standard deviation. The plant compartments were separated and placed in a forced circulation oven at 65 °C until reaching constant weight.

The specific leaf area (SLA) was determined at the ages of 60, 90 and 120 days, calculated by the ratio between the area on one side of the surface of a leaf and its dry mass. To determine AFE, all the leaves of the plant were collected, stored in a thermal container in the field and later taken to the laboratory to be digitized using the ImageJ® 1.53 software. Subsequently, they were dried in an oven at 65 °C to determine the dry mass.

Stand Uniformity

The PV50 index, proposed by Hakamada [33], was determined to assess the uniformity of the trees. For measurements at ages younger than twelve months, adaptations were made to the original formula (Equation (2)) using the cube height parameter. This was carried out due to the decrease in the error to use this variable.

$$PV50 = \frac{\sum_{k=1}^{\frac{n}{2}} Variable(ij)}{\sum_{k=1}^{n} Variable(ij)} \quad (2)$$

where

PV50: forest uniformity index,

V: volume in plot i with age j (m^3) or height^3 in plot i with age j (m^3), and

n: number of trees sorted from smallest to largest.

2.4. Statistical Analysis

The data were submitted to analysis of variance and the F test ($p < 0.10$), and averages were compared by the LSD test ($p < 0.10$). Variables were transformed by the Box–Cox method when necessary to meet the assumptions of residual normality and homoscedasticity of residual variances. Pearson's correlation coefficient was calculated for the 10% probability level ($p < 0.10$) to compare the Dickson quality index (DQI), represented by seedlings with different morphological characteristic changes between relationship growth variables, after *E.grandis x E.urophylla* plantation. The amount of seedling losses during the process was not repeated, so we presented only the total percentage of seedling losses. The data were analyzed in the SAS/STAT® 9.3 software.

3. Results

3.1. Survival and Establishment of Seedlings in the Field

The seedling mortality rate in the field 30 days after planting was affected by the morphological parameters studied (Figure 2). Treatments A and B presented a mortality rate of 3% against 8% of seedlings C and D. The total losses in each treatment during the whole silvicultural process were higher in the C treatment (24%), 15% superior to the average of the other three treatments.

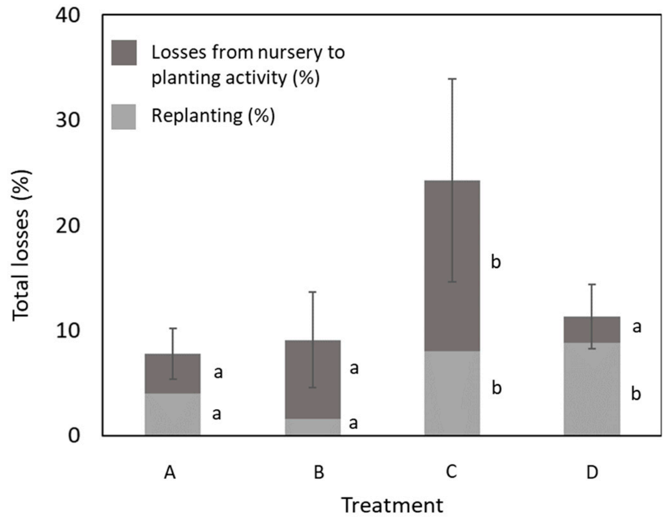

Figure 2. Seedling losses of each treatment during the whole silvicultural process, from transportation to the losses during planting, including the process of taking seedlings out of the seedling pots. Lower case letters compare the treatments within each evaluation (replanting and losses) by LSD test ($p < 0.10$).

Height and diameter were significantly affected by morphological parameters and plant age up to 120 days (Table 2). Seedlings in class C, with the lowest height in the nursery, and class E, with the highest age, exhibited lower heights four months after planting. Class C seedlings also showed significantly smaller diameter development compared to the other treatments.

Table 2. Base diameter and height at 30, 60, 90 and 120 days after planting of *E. grandis x E. urophylla* seedlings.

Treat	Base Diameter (Days)			Heigth (Days)		
	60	90	120	60	90	120
		mm			cm	
A	2.5 ± 0.1 a	4.4 ± 0.4 a	8.2 ± 0.3 a	10.6 ± 1.1 a	13.0 ± 1.3 a	39.5 ± 2.1 a
B	2.1 ±0.2 ab	4.0 ± 0.8 a	7.8 ± 0.6 ab	11.1 ± 1.8 a	12.4 ± 1.5 a	35.0 ± 3.4 ab
C	1.8 ± 0.2 bc	3.5 ± 0.7 a	7.1 ± 0.6 b	9.5 ± 0.6 a	11.7 ± 2.6 a	33.4 ± 4.0 ab
D	2.1 ± 0.1 ab	4.2 ± 0.5 a	7.4 ± 0.2 ab	9.2 ± 0.7 a	10.7 ± 1.2 a	32.1 ± 1.3 b
CV (%)	15	12	5	16	7	1
p-Value	0.0051	0.0342	0.0005	<0.0001	<0.0001	0.0003

Means followed by the same letter do not differ by the Tukey test ($p > 0.05$).

Biomass was 37, 43 and 50% lower in treatment C at 120 days after planting in the three compartments (leaf, branch + stem and root), respectively. Consequently, the total biomass was 45% lower in this treatment. Notably, high standard deviation values and coefficients of variation indicated high biomass heterogeneity among all plant components (leaves, roots, stem + branches) at this age (Figure 3).

The five classes of seedlings showed different Dickson quality indices, with the highest value observed in class E seedlings (Table 3). The specific leaf area showed significant variation between classes of seedlings at 90 days, being higher in classes C, D and E, suggesting that the dry mass of the leaves of these plants was low in relation to their area. Planting uniformity, given by the PH50 indicator, was lower in class C seedlings at 60 and 90 days of age, but these differences tend to be diluted over time (Table 3).

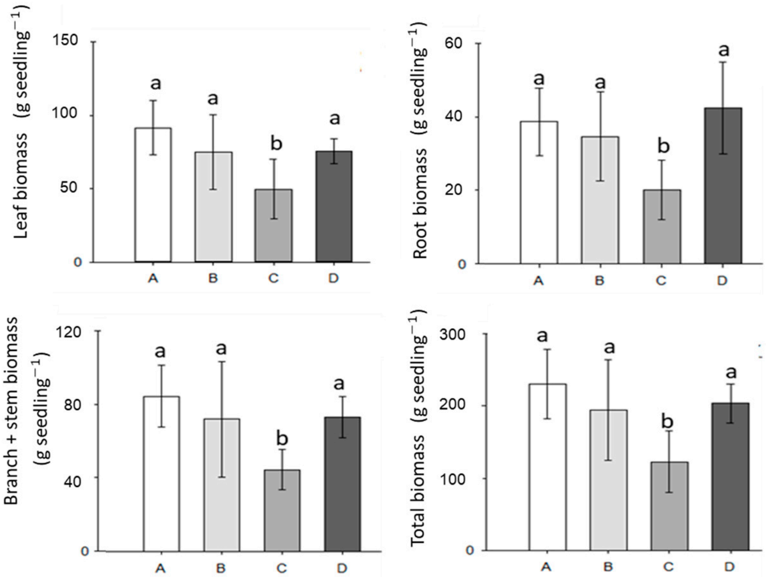

Figure 3. Dry mass of leaves, stem + branches, roots and total at 120 days after planting the seedlings. Bars indicate standard deviation. Lower case letters compare the treatments by LSD test ($p < 0.10$).

Table 3. The Dickson quality index (DQI), specific leaf area and the percentage of accumulated height of 50% of the smallest trees (PB50—Heigh^3), as a proxy of stand uniformity showing differences among seedlings characteristics from 60 to 120 days.

Treat	DQI (120 Days)	Specific Leaf Area (Days)			PH50—Heigh^3 (Days)		
		60	90	120	60	90	120
			cm^2 g^{-1}			%	
A	0.701 ± 0.109 b	18 ± 0.55	14 ± 0.43 b	15 ± 2.60 b	35 ± 2.9 ab	33 ± 1.57 ab	33 ± 1.9 ab
B	0.436 ± 0.038 c	17 ± 1.06	15 ± 1.11 b	14 ± 1.09 b	33 ± 3.9 ab	35 ± 3.81 a	33 ± 5.6 a
C	0.206 ± 0.048 d	18 ± 0.38	18 ± 1.15 a	16 ± 0.87 a	30 ± 3.7 b	27 ± 4.28 b	28 ± 3.6 b
D	0.941 ± 0.209 b	17 ± 0.99	16 ± 0.58 ab	13 ± 0.91 b	36 ± 1.2 a	35 ± 2.69 a	32 ± 6.9 a
CV (%)	14	5	5	14	9	9	13
p-Value	0.0102	0.1277	0.0019	0.0783	<0.0001	0.0032	0.0813

Means followed by the same letter do not differ by the LSD test ($p > 0.10$).

3.2. Tree Development

The stand volume was significantly affected by the morphological characteristics of the seedlings up to 64 months of age (Figure 4). Since the first measurement at 12 months, seedlings from treatment D, i.e., older seedlings, showed lower productivity, reaching approximately 12%, compared to the other three treatments. Survival after replanting was kept above 98% in all treatments until the end of rotation.

Stand uniformity, given by the PV50 index, reduced each time from 40 to 32% from 12 to 53 months, but did not differ among treatments (Table 4).

3.3. Relationship between Seedling Quality and Tree Growth

The quality of the seedlings, defined from the IQD, showed positive and significant correlations with the variables stem diameter, leaf biomass and PH50 at 60 days of age (Table 5). At later ages, significance is lost in the relationships between DQI and tree growth parameters, and it is not possible to explain the variation in volume and stand uniformity (PV50) from DQI.

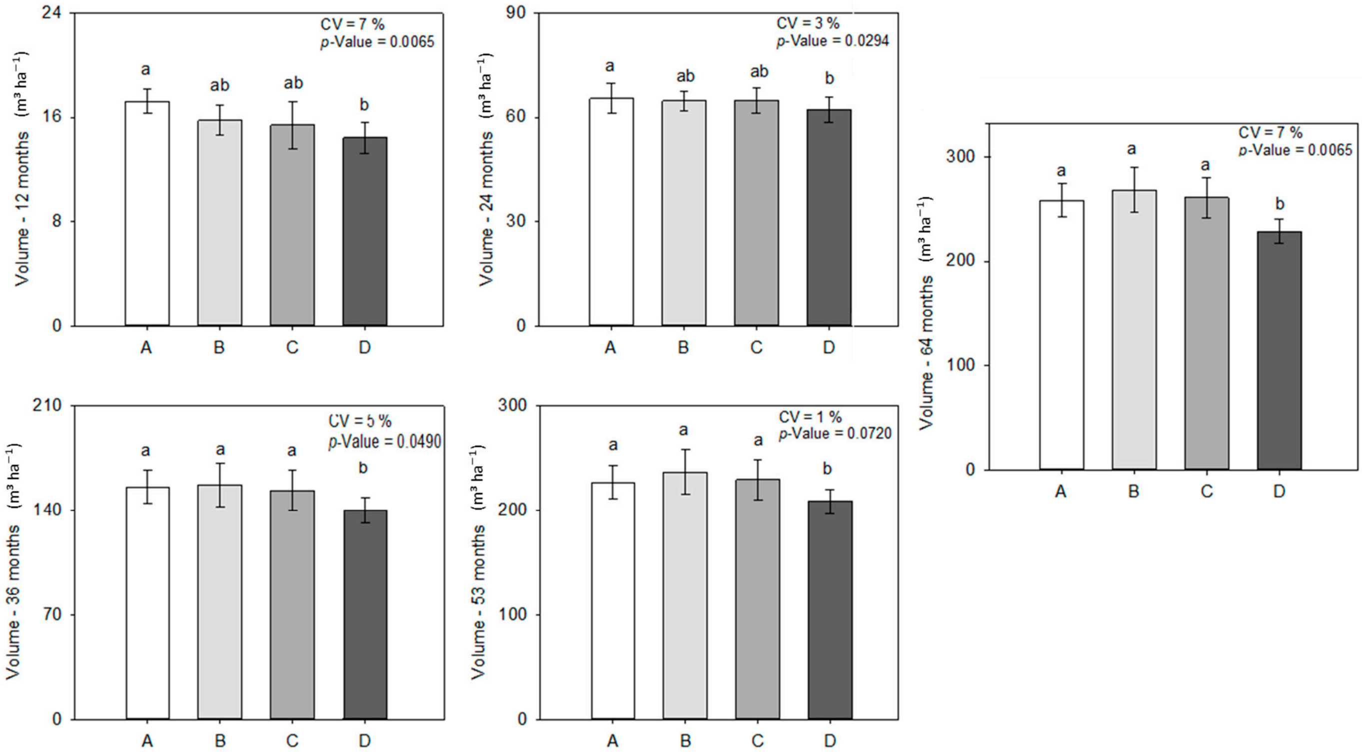

Figure 4. Wood volume at 12, 24, 36 and 53 months of age of *E. grandis x E. urophylla* plants. Means followed by the same letter do not differ by the LSD test ($p > 0.10$).

Table 4. PV50 (%) at 12, 24, 36 and 53 months in *E. grandis x E. urophylla* according to the seedling morphology showing no difference between treatments.

Treat	Cumulative Individual Volume of 50% of the Smallest Trees (Months)				
	12	24	36	53	64
			%		
A	41 ± 1.5	40 ± 1.5	35 ± 2.3	30 ± 2.4	28 ± 2.9
B	39 ± 5.6	41 ± 3.2	36 ± 4.5	32 ± 5.0	29 ± 4.1
C	39 ± 1.0	41 ± 0.8	36 ± 1.0	32 ± 1.7	30 ± 1.3
D	39 ± 3.7	41 ± 3.6	37 ± 4.1	33 ± 4.4	27 ± 4.5
CV (%)	8	5	7	9	10
p-Value	0.8497	0.9864	0.7749	0.4461	0.373

Table 5. Pearson correlation coefficients between the Dickson quality index (DQI) and observed variables of stem diameter (SD), height (H), leaf biomass (LB), SBB, RB, TB, SLA, PB50, Volume, PV50 and LAI, in the stages establishment and development of forestry.

Parameters		Pearson's Correlation Coefficient Days			
		60	90	120	-
DQI versus	SD	0.5733 *	0.484 ^{ns}	0.489 ^{ns}	-
	H	0.5077 ^{ns}	0.445 ^{ns}	0.201 ^{ns}	-
	LB	0.0356 *	0.068 ^{ns}	0.193 ^{ns}	-
	SBB	0.2763 ^{ns}	0.120 ^{ns}	0.461 ^{ns}	-
	RB	0.4639 ^{ns}	0.2748 ^{ns}	0.204 ^{ns}	-
	TB	0.2163 ^{ns}	0.150 ^{ns}	0.287 ^{ns}	-
	SLA	−0.2898 ^{ns}	−0.016 ^{ns}	−0.039 ^{ns}	-
	PH50 (H^3)	0.6340 *	0.634 *	0.625 *	-

Table 5. *Cont.*

Parameters		Pearson's Correlation Coefficient Days				
		Months				
		12	24	36	53	64
DQI versus	Volume	-0.292^{ns}	-0.301^{ns}	-0.134^{ns}	-0.044^{ns}	-0.281^{ns}
	PV50	-0.069^{ns}	-0.312^{ns}	-0.325^{ns}	-0.201^{ns}	-0.246^{ns}

* = $p < 0.10$ and ns = $p > 0.10$.

As the evaluations progressed and aged, a noticeable trend emerged regarding the relationship between volume at the end of the short rotation and the preceding years. Initially, in the first year, no discernible correlation was observed. However, as the evaluations advanced, a significant increase in the coefficient of determination was observed, indicating a stronger association with the age of the plantation (Figure 5).

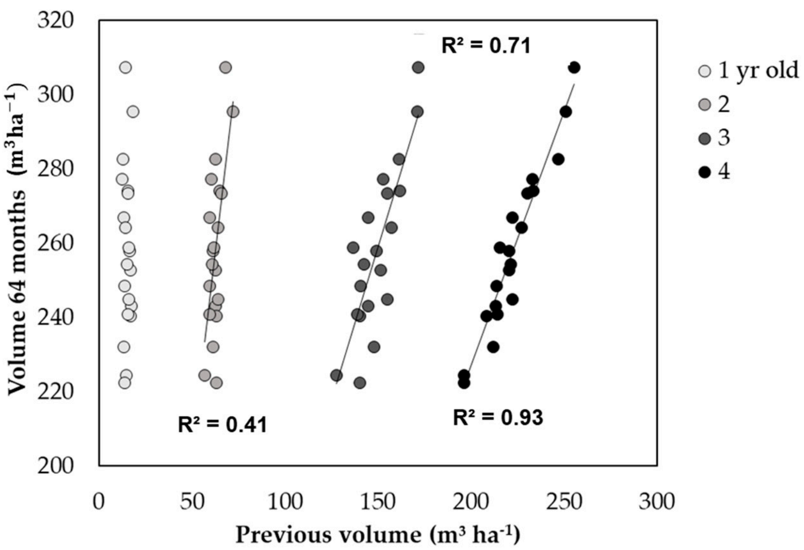

Figure 5. Relationship between volume at the end of rotation and in different years.

4. Discussion

We confirm our first hypothesis that prime quality seedlings will experience fewer losses throughout the entire process encompassing transportation, handling, and planting operations, including the removal of seedlings from pots. An important operational implication arises from the significant amount of seedling losses observed. Particularly, treatment C, representing under prime seedlings, exhibited a 15% higher loss compared to the other treatments. South et al. [34] showed that for *Pinus*, many problems can justify the losses, for example in transportation or during the process of removing seedlings from containers. To put this into perspective, considering a planting area of 1000 hectares with a stocking density of 1300 seedlings per hectare and an average loss rate of 9%, there would be a total loss of 117,000 seedlings. However, if treatment C seedlings were used, the loss would increase to 312,000 seedlings. This additional loss of approximately 200,000 seedlings highlights the substantial impact it would have on the system. Considering both the financial costs and the sustainability aspects of the system, it becomes crucial to prioritize the planting of prime seedlings (A and B standards). This decision is essential because the loss of seedlings not only results in a waste of resources but also leads to increased consumption of water, fertilizers, and fuel.

We partially confirm the second hypothesis that prime quality seedlings will exhibit higher survival rates, uniformity, and growth from the beginning to the end of the rotation period. Survival was higher in seedlings A and B with 97% at 30 days after planting, and C and D with 92% of treatments, but all treatments kept a higher survival above 98% after replanting. Among the factors that can explain the difference in survival in the field are the physiological mechanisms. The two main physiological mechanisms that plants have to avoid water loss are stomatal closure and leaf area reduction, which consists of increasing the thickness and reducing its mass, thus reducing its specific leaf area [35]. Seedlings "A" and "B" at 90 days showed a smaller specific leaf area, indicating less water loss and consequently better adaptation in the field. This is a factor that may explain the lower mortality rate of these two molt patterns and also the better growth in height and diameter when compared to standard "C" molt at 90 days. A study [36] showed that to achieve more productive planting at four years of *Pinus elliotti* and with greater survival, seedlings with a larger collar diameter should be selected. However, the collar diameter did not significantly influence survival and productivity in field plantations [30]. Our work showed that in seedlings within the ideal planting age (up to 100 days), the stem diameter can be a determining factor of survival. However, when we consider seedlings with more time in the nursery, this parameter cannot be used to predict survival in the field, since the mortality rate of seedlings with more than 5 mm in diameter was 3-fold higher than that of seedlings with 2.5 mm to 4.5 mm in diameter. Lower wood growth should be expected if replanting was not carried out but replanting after 30 days of planting is a current operational activity, so the decision was to compare treatments in a "real world" silviculture.

At 90 days, it was also possible to observe a statistical difference in the uniformity, indicating that outplanting with "C" and "D" seedlings presented greater heterogeneity. According to [33], every 1% of PV50 reduction at the beginning of rotation can causes a loss of 4.5 m^3 ha^{-1} $year^{-1}$ at the end of rotation. This shows how planting uniformity can affect the growth and productivity of *Eucalyptus* forests. It is interesting to obverse that there is no difference in the uniformity among treatments from 12 months until the end of rotation. We speculate that besides a lower-quality seedling in treatment B, especially C and D, all seedlings were uniform, which did not allow intraspecific competition that could create dominant and dominated trees [37,38].

A few studies followed tree growth until the middle to the end of rotation, many of them in the *Pinus* plantation [39–41]. The authors of [31] found a reduction of 42% of the mean annual increment from the best to the worst treatments (25×43 m^3 ha^{-1} yr^{-1}) in *Pinus taeda* at 9 years after planting. This study showed that one of the main reasons for the loss of productivity was the age of seedlings, corroborating our results, where treatment D had 12% less productivity. As plants mature and their age increases, there is a negative impact on their survival and growth that could be partially attributed to the presence of brown roots, which reduces their capacity to efficiently absorb water [42]. Two subsequent studies focusing on the growth of mature trees yielded similar findings, demonstrating that the impact of a particular effect administered during the seedling stage did not exist or diminished over time. This phenomenon aligns with the outcomes of our current investigation, wherein, after a span of 36 months, only seedlings categorized as 'D' exhibited notable differences to the other treatment groups. In the case of *Eucalyptus pilularis* [43], a span of three years following planting saw no effect of seedlings hardened by irrigation rate reduction during the nursery phase. Another observation emerged in a study of *Eucalyptus dunnii* [44]. Until 3 years after planting, seedlings with larger plug volumes (measuring 103 cm^3 per seedling) exhibited higher growth compared to their conventional plug counterparts (measuring 60 cm^3). However, beyond this point, the beneficial effects disappeared.

Forest science is actively striving to advance its understanding of the characteristics of *Eucalyptus* plantations obtained during the seedling phase, aiming to establish correlations with the final rotation and ultimately enhance silviculture practices. Notably, the early selection of trees in the breeding process serves as a clear example of this pursuit [45,46]. However, our study findings reveal that even seemingly straightforward factors such as seedling quality do not necessarily exhibit a correlation between seedling variables and growth during the final rotation, rejecting our third hypothesis. This highlights the importance of scientists thoroughly analyzing results obtained at the beginning of the rotation before drawing conclusions. A specific example from our research pertains to the morphological aspect of root biomass, which has been extensively studied in seedlings, with previous works indicating its influence on initial growth after outplanting [47–49]). In our study, treatment C exhibited a lower initial biomass; however, by the end of the rotation, it did not differ significantly from seedlings A and B. Conversely, treatment D, despite having a similar root biomass in the initial evaluations (up to 120 days), demonstrated a lower volume at the end of the rotation. This discrepancy highlights the complex nature of seedling evaluation and emphasizes the need for careful consideration of field variables when drawing conclusions. Additionally, the widely utilized Dickson quality index, commonly employed to assess seedling quality, did not establish a clear relationship with the field variables in our study. This suggests that it may not be the most suitable method for evaluating seedling quality in *Eucalyptus* clonal plantations. It is worth noting that the Dickson quality index was originally designed to evaluate gymnosperm species in a temperate climate [22], which may differ from the tropical areas where our experiment was conducted.

5. Conclusions

This is one of the first studies to follow the survival, uniformity and growth of *Eucalyptus* seedlings from the nursery to the end of a short rotation. Notably, it highlights the significant impact of selecting prime seedlings in the nursery on both productivity and the overall sustainability of the business. It was observed that with under prime seedlings (treatment C), a considerably higher loss of seedlings occurred during the planting process (24% compared to 9% in the other treatments). On the other hand, old seedlings (treatment D) exhibited a 12% reduction in wood growth in the final rotation stage. These findings emphasize the importance of careful selection and management of seedlings during the nursery phase, directly affecting the long-term productivity and success of the plantation.

Furthermore, when considering the objective of proposing silvicultural prescriptions, it is recommended that measurements extend to at least until the mid-rotation stage. This is crucial as it allows for a more accurate representation of values that align with the final rotation outcomes. By extending the duration of measurements, researchers can gather more reliable data and subsequently develop more effective and informed silvicultural strategies.

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