





Initial Growth and Quality of *Toona ciliata* Seedlings under Different Substrates

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Abstract

In producing forest seedlings, the use of residues may be an option to improve seedling quality. Thus, the objective of this study was to evaluate the initial growth and quality of *Toona ciliata* seedlings on different substrates. The experimental design was completely randomized with seven treatments consisting of commercial substrate (CS), vermicompost (VC), urban waste compost (UWC) and mixtures in proportions of 50% (CS + VC, CS + UWC and VC + UWC) and 33% (CS + UWC + VC), with twelve replications. The use of substrates composed of organic residues 120 days after sowing shows potential for producing *Toona ciliata* seedlings. The combination of substrate components provides higher seed growth and quality than unmixed substrates. Compositions of 50% UWC or 50% VC + 50% CS are efficient in growth and seed quality.

Keywords: vermicompost, urban waste compost, Australian red cedar.

1. INTRODUCTION AND OBJECTIVES

One of the primary factors for implementation and planting of highly productive forest stands is seedling quality. Therefore, many efforts have been made to better seedling quality and reduce its final production value. An alternative would be the employment of organic materials as substrates, and interesting solution to reduce urban waste. Furthermore, is an effective way of reducing the high-cost of inputs needed to produce forest seedlings (Trazzi et al., 2013).

Among the organic materials that can be used as substrate for producing forest seedlings, urban waste compost has shown potential as an alternative substrate in producing *Eucalyptus grandis* seedlings (Silva et al., 2014). Silva et al. (2014) report an improvement in the physical quality of the substrate, while Krob et al. (2011) highlight the potential of this compound in improving the chemical quality of the soil because of the increase in pH values, CEC, total N, organic C levels, extractable P and Na, exchangeable Ca and Mg, as well as a reduction in exchangeable Al levels.

Another raw material source for this type of substrate compound is vermicompost. Produced by organic waste with the help of earthworms, this material has a compound with high nutritional value as a final product, mainly containing P, Ca, Mg and K (Cunha et al., 2015).

Regarding forest species with high economic potential, Australian red cedar (*Toona ciliata* M. Roem var. *australis*) is an exotic species belonging to the Meliaceae family which has been cultivated in Brazil for almost three decades (Ferreira et al., 2012). This species has a botanical similarity to native Brazilian cedar (*Cedrela fissilis*) and mahogany (*Swietenia macrophylla*) (Pinheiro et al., 2006), but its main advantages is the resistance to *Hypsipyla grandella* larvae, a pest that attacks the apical bud of the Meliaceae family. Moreover, it has a short production cycle with an average annual increase of up to 30 m³ ha⁻¹ year⁻¹ (Ferreira et al., 2012; Vilela & Stehling, 2012).

Based on the importance of implementing renewable materials for composing substrates and the scarcity of studies covering this theme, especially regarding *Toona ciliata*, the objective of this study was to evaluate the initial growth and quality of *Toona ciliata* seedlings on different substrates.

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2. MATERIALS AND METHODS

The study was conducted in a greenhouse at the Agronomy and Environmental Sciences Department of the Federal University of Santa Maria, Frederico Westphalen Campus, in the northern region of Rio Grande do Sul state in the municipality of Frederico Westphalen, located at a medium altitude of 465 m, latitude 27° 23' 47" South and longitude 53° 25' 41" West. The region's climate is Cfa following the Köppen classification, corresponding to a mild temperate climate with hot summer (Alvares et al., 2013).

The experimental design was completely randomized with twelve replicates (each replicate composed of six seedlings) and seven treatments, with commercial substrate (CS), vermicompost (VC) and urban waste compost (UWC) being used individually and mixed in proportions of 50% (CS + VC, CS + UWC and VC + UWC) and 33% (CS + UWC + VC). A sample was taken for chemical analysis after mixing the substrates, being characterized following Tedesco et al. (1995) (Table 1).

H. Decker® was used as the CS, which is composed of peat, charcoal rice husk and additives (0.04% N and P₂O₅, 0.05% K₂O and 2.73% calcitic limestone). UWC was obtained from composting the organic part of urban waste (food waste, napkins and fruit peels) manually separated at the solid waste recycling plant, which receives the waste from the consortium of municipalities in the Médio Alto Uruguai region, in Seberi, RS. VC was produced from solid bovine manure, together with other organic materials such as fruit peels, leaves and grass for 120 days using *Eisenia andrei* worms. The UWC and VC were sieved (5 mm) before filling the tubes.

T. ciliata seeds (from parent trees) were purchased from the Silviculture Laboratory of the Forest Research Society

(SIF) in Viçosa, Minas Gerais. The lot was first subjected to a preliminary analysis to eliminate any impurity. The sowing was done in polypropylene tubes (in their respective treatments) with a depth capacity of 125 cm³ to 0.5 cm, using three seeds per tube. A thinning was done after 30 days of sowing with only one seedling remaining, considering the visual aspect (without measurements) of greater vigor and phytosanitation as criteria.

The study was conducted for four months (August and November 2015), during which no fertilizer was applied to the studied substrates. Irrigation was performed by time-activated sprinklers in the early morning at 6 a.m. and the last at 6 p.m., with each irrigation lasting 12 minutes, and a 2-hour interval between them, comprising an 8 mm volume of water daily. The maximum and minimum temperatures and accumulated precipitation in the experiment period was obtained from the automatic meteorological station of the National Institute of Meteorology (INMET), linked to the Agroclimatology Laboratory of Frederico Westphalen Campus, RS, 200 meters from the experiment (Table 2).

The following were evaluated 120 days after sowing: seedling height (H); stem diameter (SD); root-specific surface area (SSA); shoot dry mass (SDM); and root dry mass (RDM). The seedling height was measured from the substrate level to the main stem apex using a graduated ruler and the SD with a digital hardness caliper (Stainless Hardene®) at the seedling stem base. For determining SDM and RDM, boBrth parts were separated at the stem height and oven dried at a temperature of 60 ± 5 °C until constant mass. The total dry mass (TDM) was subsequently calculated from the sum of SDM and RDM. Regarding SDM and RDM, the N, P and K concentrations were determined after the milling following the methodology of Tedesco et al. (1995).

Table 1. Available nutrient contents, pH in water (1:1), organic carbon (C-org) and base saturation (V) of the commercial substrate (CS), urban waste compost (UWC) and vermicompost (VC) used in producing *Toona ciliata* seedlings.

Substrate	pH (H ₂ O)	P	K	Ca	Mg	C-org	V
	(1:1)	mg L ⁻¹		cmolc L ⁻¹		%	
CS	5.2	384.9	858	37.1	17.1	32.6	92.0
UWC	7.1	87.5	1.110	21.5	4.8	11.0	96.7
VC	7.2	132.0	4.278	13.9	17.2	15.4	95.4
CS + UWC ⁽¹⁾	6.3	116.1	1.392	35.2	10.5	12.9	96.1
CS + VC ⁽¹⁾	5.9	228.4	1.362	30.4	22.9	22.3	94.2
VC + UWC ⁽¹⁾	7.0	95.7	2.940	18.7	12.2	12.7	96.5
CS + VC + UWC ⁽²⁾	6.8	91.5	2.478	23.3	13.1	15.7	95.1

⁽¹⁾ Proportion of 50%; ⁽²⁾ Proportion of 33%.

Table 2. Maximum and minimum temperatures and accumulated precipitation during the experiment period.

Month	Temperature °C		Total precipitation (mm)
	Maximum	Minimum	
August	26.5	15.3	33.0
September	24.5	13.7	65.8
October	26.3	16.7	188.6
November	26.2	17.1	368.0

Source: Automatic meteorological station of the Instituto Nacional de Meteorologia (INMET), Frederico Westphalen, 2015

The SSA was estimated by Equation 1 from Tennant (1975):

$$SSA = 2\pi \times RR \times L \quad (1)$$

In which SSA: specific surface area; L: root length; and RR: root radius.

Equation 2 was used for calculating root radius:

$$RR = \frac{\sqrt{V}}{L \times \pi} \quad (2)$$

In which V: volume (green mass of the root system); L: estimated following Tennant (1975), implementing Equation 3:

$$L = \text{number of intersections} \times CF \quad (3)$$

In which L: root system length; CF: correction factor (0.7857).

From the evaluated morphological parameters, the ratio between H/SDM and the Dickson quality index (DQI) proposed by Dickson et al. (1960) was calculated by Equation 4:

$$DQI = \frac{TDM}{\frac{H}{SD} + \frac{SDM}{RDM}} \quad (4)$$

The relative efficiency (RE) of the proposed treatments (PT) regarding the commercial substrate (CS) was calculated by Equation 5:

$$RE(\%) + \frac{CS - PT}{CS} \times 100 \quad (5)$$

Normality and homogeneity of variance tests were done by the Shapiro-Wilk and Bartlett tests, respectively, to meet the assumptions of analysis of variance. The equation $\sqrt{x+1}$ was used, for which the data needed to be transformed (for the H/SDM and DQI ratio). Once the mathematical assumptions were accounted for, the analysis of variance was performed and the means of the treatments were compared by the

Scott-Knott test at 1% error probability, using the SISVAR statistical program (Ferreira, 2016).

3. RESULTS AND DISCUSSION

The analysis of variance showed significant effects ($p \leq 0.01$) for the substrates used and their combinations in the initial development of *T. ciliata* seedlings (Table 3). The CS + UWC mixture provided a larger stem diameter (4.92 mm) than the others. Although studies with eucalyptus indicate that seedlings for field planting should have a minimum diameter of 2 mm (Wendling & Dutra, 2010), there is no information on the minimum recommended value for *T. ciliata*. However, Moreira & Moreira (1996) state that the stem diameter is recognized as one of the best quality standard indicators for seedlings, so the higher the value, the greater the chance of post-planting survival in the field. As such, we can observe (Table 3) that the stem diameter was superior for all the combined substrates when compared to the isolated ones.

The UWC and VC used individually or in combination with CS produced the highest seedling heights when compared to the exclusive use of CS, highlighting the CS + UWC mixture, which statistically provided superior seedling height to the other substrates (17.19 cm) (Table 3). For Gomes & Paiva (2006) and Wendling & Dutra (2010), the height in good quality seedlings for field planting is between 15 and 30 cm. With the exception of CS, the other substrates presented height within the range or close to the minimum value suggested by the authors. This result demonstrates the organic residue substrates potential for producing forest seedlings, as well as providing good seedlings development, which can reduce their production costs by substituting commercial substrates and sometimes fertilizers.

The shoot dry mass was statistically superior when VC and CS + VC were used, whereas UWC favored significantly higher phytomass production for the root dry mass of the *T. ciliata* seedlings. Moreover, the total dry mass was significantly higher in the UWC and CS + VC substrates. The lowest averages for the dry mass of *T. ciliata* seedlings were obtained with the use of CS (Table 3). Padilha et al. (2018) also observed lower dry mass in *Peltophorum dubium* seedlings in commercial substrate when compared to organic substrate. For Gomes & Paiva

(2006), root mass is an important parameter to be evaluated, since it influences the survival and initial development of the seedlings in the field; the more abundant the root system, the greater the seedlings survival. All the proposed substrates favored higher root mass production compared to CS, which increases the survival chances of post-planting seedlings and consequently lower replanting cost.

The specific surface area of the seedling roots was higher with the VC + UWC mixture but did not differ significantly

from CS + VC, CS + UWC or CS + UWC + VC (Table 3). To Silva et al. (2011), the specific surface area is a highly important parameter for obtaining a root system with greater nutrient absorption capacity. This is because, as Tennant (1975) states, a root system with the highest specific surface area for the same root mass will have a higher number of fine roots, and consequently greater nutrient absorption capacity. Therefore, the results of this study show that the VC and UWC substrates enabled a higher specific surface area when compared to CS.

Table 3. Stem diameter (SD), height (H), shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM), specific surface area (SSA), height-shoot dry mass ratio (H/SDM) and the Dickson Quality Index (DQI) of *Toona ciliata* seedlings produced in different proportions of commercial substrate (CS), urban waste compost (UWC) and vermicompost (VC).

Substrate	SD	H	SDM	RDM	TDM	SSA	H/SDM	DQI
	mm	cm		g plant ⁻¹		cm ²		
CS	2.32 c*	6.24 d	0.24 d	0.15 d	0.39 d	27.31 c	26.39 a	0.09 c
UWC	2.44 c	15.94 b	1.19 b	1.03 a	2.22 a	41.79 b	13.88 c	0.29 b
VC	2.37c	14.13 c	1.35 a	0.72 c	2.07 b	46.01 b	10.51 d	0.26 b
CS + UWC ⁽¹⁾	4.92 a	17.19 a	0.99 c	0.79 c	1.78 c	50.77 a	17.61 b	0.37 a
CS + VC ⁽¹⁾	2.74 b	15.35 b	1.35 a	0.92 b	2.27 a	52.85 a	11.45 d	0.34 a
VC + UWC ⁽¹⁾	2.64 b	14.38 c	1.24 b	0.88 b	2.13 b	53.99 a	11.67 d	0.31 b
CS + UWC + VC ⁽²⁾	2.63 b	15.66 c	1.27b	0.79 c	2.06 b	51.77 a	12.40 d	0.27 b
CV (%)	8.15	11.25	12.52	13.50	10.32	13.42	15.99	24.28

* Means followed by the same letter in the column did not differ statistically by the Scott-Knott test at 1% probability of error. ⁽¹⁾ Proportion of 50%; ⁽²⁾ Proportion of 33%.

The lowest H/SDM ratio was obtained with the use of VC, similar to the CS + VC, VC + UWC and CS + UWC + VC compositions (Table 3). For Gomes et al. (2003), the lower the quotient obtained by dividing the height by the shoot dry mass, the more lignified the seedling will be and the greater its survival in the field. As such, all the proposed substrates favored the production of more hardened off *T. ciliata* seedlings when compared to CS.

UWC and VC substrates used individually or mixed with CS (CS + UWC and CS + VC) provided higher DQI when compared to CS used individually (Table 3). The DQI is regarded by Fonseca et al. (2002) as one of the best seedling quality indexes considering robustness and biomass distribution balance of the seedlings in the calculation, weighing the results of several important attributes in a single index. Vieira et al. (2014) found DQI values between 0.06 and 0.56 for *Anadenanthera falcata* seedlings, while Gonzaga et al. (2016) found values between 0.51 and 0.77 for *Hymenaea courbaril* seedlings. This shows that the DQI varies depending on species, seedling management, substrate used, seedling age, among other factors. However, to Faria et al. (2013a), the higher the DQI value the better the seedling quality, which was achieved by mixing CS with UWC or VC. Producing quality seedlings can determine the success of a forest stand, since the seedling characteristics can indicate the

quality of the produced trees. Moreover, they must withstand soil and climatic adversities encountered in post-planting field, present a low percentage of mortality and exhibit rapid growth and initial development, and consequently a reduction in the cultivation practices of the newly established stand.

The relative efficiency study showed that the proposed substrates were superior compared to the CS, with the CS + UWC mixture showing relative efficiency of 112, 175 and 312% for the stem diameter, height and Dickson quality index of the *T. ciliata* seedlings (Figure 1). The exclusive use of CS resulted in lower development and quality of *T. ciliata* seedlings. In studies by Silva et al. (2017), different responses were observed for *Pinus elliottii* and *Eucalyptus grandis* seedlings in vermicomposting substrates and proportions with commercial substrate, in which the commercial substrate was superior to the proposed substrates for *P. elliottii*, presenting negative relative efficiency, while mixtures above 20% of the vermicompost to the commercial substrate presented higher relative efficiency for the height and stem diameter of *E. grandis* seedlings. This shows the importance of choosing the substrate, for as Jabur & Martins (2002) state, it is the root system developed that determines the shoot growth of the seedling, and it is therefore necessary to carefully chose the substrate and their proportions for each forest species.

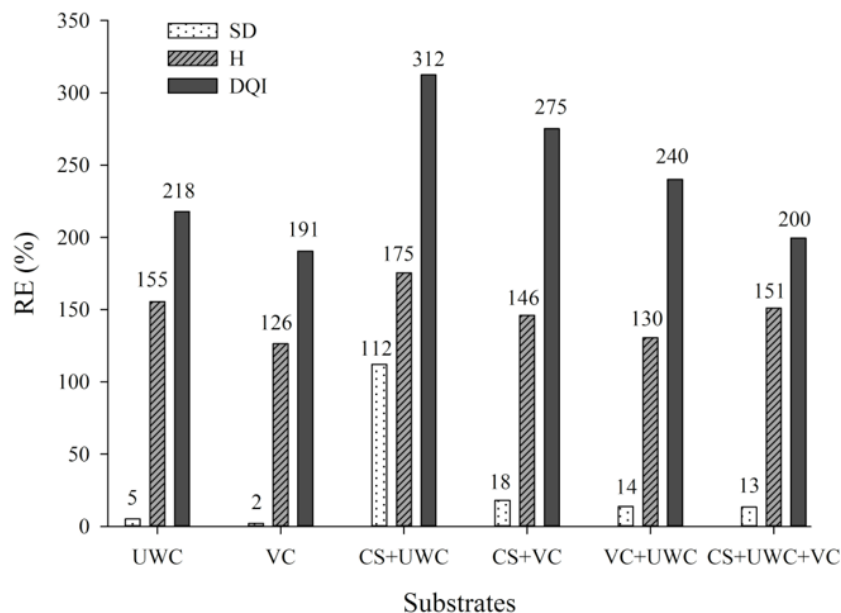


Figure 1. Relative efficiency (RE) of the urban waste compost (UWC) and vermicompost (VC) used individually and in mixtures compared to the commercial substrate (CS) for stem diameter (SD), height (H) and Dickson quality index (DQI) of *Toona ciliata* seedlings.

Moreover, research results with *Sesbania virgata* and *Senna alata* show that the best substrates for seedling production do not come from isolated materials, but from compositions of different substrates (Delarmelina et al., 2013; Faria et al., 2013b). The CS + UWC and CS + VC mixtures generally provided the highest averages of the morphological parameters and better seedling quality under the conditions of this study, being therefore the most indicated substrates for producing *T. ciliata* seedlings.

The lower values of initial development and quality parameters of the *T. ciliata* seedlings obtained with CS can be associated with the lower pH (5.2) (Table 1), since as stated by Braga et al. (2015), *T. ciliata* species are not acid-tolerant. The appropriate substrate pH must be at least 6.0, according to Brasil (2009). The growth potential of seedlings of forest species can be achieved when acidity and nutrient availability are adequate, associated with the use of substrates with suitable physical characteristics (Da Ros et al., 2015; Melo et al., 2014; Santos et al., 2014). Moreover, although CS presents initially similar or even higher nutrient contents than the other substrates, except for K (Table 1), it is possible that higher leaching occurs because of rice husk in its composition and therefore lower availability of nutrients during the seedling production process, thereby requiring greater need for seedling replacement.

The nutrient availability of the substrates characterized immediately before sowing *T. ciliata* (Table 1) are suitable based on the indication of Sociedade Brasileira de Ciência do Solo (SBCS, 2016), and probably did not contribute to

the difference in seedling development. However, different types of organic materials used in composting (UWC) and vermicomposting (VC) substrates can potentiate different nutrient release rates during the initial development period of seedlings.

The total amount of carbon and nutrients present in organic materials and the relationship between them is one of the main factors that influence nutrient release rate as a function of cultivation time, with nitrogen being the most affected by this process (Figueiredo et al., 2012; Fioreze et al., 2012). Organic compounds usually vary in the amount of total nutrients and organic carbon (Da Ros et al., 2015; Santos et al., 2014). This variation may provide a greater or lesser amount of nutrients during the development period by the mineralization process, since a rapid leaching of available nutrients occurs in the seedling production system in tubes with periodic irrigations. As for CS, the nutrient availability during the study period was probably lower than the other substrates because the CS composition used had rice husk which, as Guerrini & Trigueiro (2004) state, is poor in nutrients.

Substrates with adequate nutrient contents and their availability throughout the seedling production process are desirable, as they will reduce fertilization rates and fertilizer costs.

Nitrogen levels in *T. ciliata* shoot and root system were lower in the CS treatment, with values of 14.4 and 12.1 g kg⁻¹, respectively (Table 4), while its content in the other treatments varied between 17.7 and 20.5 g kg⁻¹ in the shoot dry mass, and between 17.7 and 23.1 g kg⁻¹ in

the root dry mass. In a study with the same forest species after 150 days of transplantation into pots with 3.0 L of soil, Moretti et al. (2011) found nitrogen contents in the shoot dry mass between 15.2 and 22.3 g kg⁻¹ in the treatments without nitrogen restriction, and of 8.7 and 9.8 g kg⁻¹ in the treatments with nitrogen restriction. The authors emphasize that nitrogen was the nutrient which most restricted the

seedling development, which may also have affected the seedling development in the present study because of the lower nitrogen content found in the dry mass of the CS treatment. This is probably related to the lower release rate of this element (by the mineralization process) during the conduction of the experiment, being associated with the types of organic materials which compose this substrate.

Table 4. Nitrogen, phosphorus and potassium content in shoot dry mass (SDM) and root dry mass (RDM) of *Toona ciliata* seedlings produced in commercial substrate (CS), urban waste compost (UWC) and vermicompost (VC).

Substrate	Nitrogen		Phosphorus		Potassium	
	SDM	RDM	SDM	RDM	SDM	RDM
	g kg ⁻¹					
CS	14.4 f*	12.1 e	8.8 a	10.3 a	21.0 b	10.8 e
UWC	19.4 b	23.1 a	6.8 b	8.3 d	19.5 c	14.3 a
VC	20.5 a	19.6 c	6.5 b	9.5 b	21.5 a	14.5 a
CS + UWC ⁽¹⁾	18.7 c	20.1 c	4.8 e	7.3 f	17.3 d	12.3 c
CS + VC ⁽¹⁾	17.7 e	20.7 b	5.8 d	8.3 d	16.8 e	13.5 b
VC + UWC ⁽¹⁾	18.3 d	17.7 d	6.3 c	8.5 c	16.5 f	11.5 d
CS + UWC + VC ⁽²⁾	18.3 d	17.3 d	5.5 d	7.8 e	16.0 g	10.8 e
CV (%)	1.16	2.07	2.45	1.44	1.23	1.27

* Means followed by the same letter in the column did not differ statistically by the Scott-Knott test at 1% probability of error. ⁽¹⁾ Proportion of 50%; ⁽²⁾ Proportion of 33%.

Phosphorus contents in both parts of the seedlings were statistically higher in the CS treatment (Table 4), being directly related to the higher content available in this substrate (Table 1). However, the lowest averages of morphological variables and quality indexes of *T. ciliata* seedlings were obtained in this treatment (Table 3), which did not appear to have significantly influenced these results. The variation in the phosphorus content in the shoot dry mass was between 4.8 and 8.8 g kg⁻¹, higher than those found by Moretti et al. (2011) in *T. ciliata* cultivation with adequate nutrient availability. This indicates that this element probably did not limit the initial seedling development. The “very high” levels of phosphorus available in all substrates at the sowing time, as indicated by the SBCS (2016), probably ensured adequate availability of the nutrient throughout the production period.

Regarding the potassium contents in the dry mass of the *T. ciliata* seedlings, the VC treatment provided a higher average for the shoot, while the VC and UWC treatments presented a higher average for the root system (Table 4). Regardless of the significant difference between the treatments, the potassium contents in the shoot dry mass were similar to those found by Moretti et al. (2011) without nutrient restriction, indicating that this element was probably also not limited in the seedling production in the present study because of the high contents present in all the substrates (Table 1).

These results evidenced different responses for the initial development and quality of the *T. ciliata* seedlings regarding the composition of alternative substrates. Therefore, the importance of choosing the right substrate composition for seedling production of tree species is confirmed since it is a preponderant factor in the formation and standardization of seedlings. As Da Ros et al. (2015) state, the substrates have influence on both germination and seedling development of tree species.

The organic residue substrates showed potential when used to produce *T. ciliata* seedlings, providing better quality and development during the nursery phase. Thus, they enable the seedlings to reach the desired dimensions in less time and with less investment in substrates, fertilizers and irrigation, thereby guaranteeing a higher financial return.

4. CONCLUSIONS

Under the conditions of this study, substrates composed of organic residues show potential for producing *Toona ciliata* seedlings.

The combination of substrates provides higher initial development and quality of *Toona ciliata* seedlings than substrates with a single component.

The 50% mixture of urban waste compound or 50% vermicompost with a further 50% commercial substrate is

efficient in the initial development and quality of *Toona ciliata* seedlings and can replace the pure commercial substrate.

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