Study on the viability of incorporation of the water treatment plant sludge in the substrate for the production of native species to the Atlantic Forest (Brazil)

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RESUMO

Sludge is considered the main residue of a Water Treatment Plant (WTP) and its inadequate disposal can cause serious damage to human health and the environment. Thinking about the reuse of this waste is not only an adaptation of the current legislation, but also an economic and environmental gain. Therefore, this research analyzed the feasibility of incorporation of Water Treatment Plant Sludge (WTPS) in the substrate for seedlings production of native species of the Atlantic Forest, by verifying the quality of the seedlings by the survival rate, growth rate and Dickson Quality Index (DQI). Economic and environmental assessments were also carried out. For this, traits with variation of WTPS and SS were used (T2 100% WTPS, T3 with 75% WTPS and 25% SS, T4 50% WTPS and 50% SS, T5 25% WTPS and 75% SS and T6 100% SS), in addition to the control treatment (T1 50% WTPS and 50% commercial soil). Analyzing the results it was verified a high survival rate of all the seedlings in the traits used. The averages of the growth rates were higher in T1, T5 and T6. The T5 trait presented the highest result in relation to DQI. Analyzing the environmental economic approach, the Sanitation Company would no longer annually acquire 7,500 m³ of a soil and would not land 3,750 m³ of waste per year. In addition to the environmental gain, the avoided cost can be around US $ 48,000.00 per year.

1. INTRODUCTION

The main waste of a Water Treatment Plant (WTP) is the sludge and its inadequate disposal can cause serious damage to human health and the environment. In Europe, millions of tonnes of Water Treatment Plant Sludge (WTPS) are produced annually (Basibuyuk *et al*, 2004). Di Bernardo (2012) states that the problem of WTPS is worldwide and its characteristics vary according to a locality that is a watershed is also inserted. The final disposal alternatives can vary according to the country where WTP is located; for example in some countries from Europe and North America, the freezing of the WTPS is a common alternative, whereas in Brazil and other developing countries it is decided to dispose of this waste in landfills or even to wrongly discard them on the ground.

Several alternatives of WTPS disposal can be employed and the knowledge of the characteristics of this residue becomes essential to define its best destination. Furthermore, it is known that environmental laws are increasingly restrictive in relation to waste disposal (Hsieh et al, 2008) and in this case, the context of the WTPS destination is inserted. Thus, the proposition of alternatives that allow the valorization of waste as a raw material is a worldwide trend in the present day (Pozzobon, 2013).

Several studies on the beneficial use of WTPS have been developed in the world. In the United States, some states already have their own legislation to encourage their reuse, such as the state of Colorado, where since 2004 there is a legislation that regulates this practice, promulgated by the Department of Public Health and Environment (Colorado, 2004). Brazil does not have specific legislation for the use of WTPS, but it has two important legal aspects that should be considered:

i) Federal Law 12.305/2010 that establishes the National Solid Waste Policy (NSWP) and prioritizes the reuse and recycling of solid waste and the reduction of its destination to the landfill (Brazil, 2010); ii) Resolution 357 of the National Environment Council – CONAMA, 2005, which defines criteria and procedures for the agricultural use of Sewage Sludge (SS) generated in Wastewater Treatment Plants (WWTP) (Brazil, 2005). The first deals with solid waste in general and mentions the need for reuse and recycling of these taken as a whole. Although the second one addresses SS, it is emphasized here that this theme has been studied in Brazil and that this legislation is under review.

During the development of this study, it was observed that most of the researches on the subject aim at the study of the applicability of the WTPS in the civil construction as incorporation in the ceramic industry and in the cement manufacturing. According to Ahmad et al (2016), studies have also been carried out for its use in the recovery of degraded areas and nutrient reduction in soils. It is also known the relevance of studies aimed at the use of WTPS in arable areas. However, few studies related to the incorporation of WTPS in the production of seedlings were found in the review (Neto, 2011 and Augusto, 2016).

According to the exposed scenario and in the context of the main damages that the inappropriate disposal of WTPS can cause in the environment, the present study aims to analyze the feasibility of incorporation of WTPS in the substrate for the production of native species to the Atlantic forest. The study also relates the possibility of reducing the consumption of natural resources with the cost of the destination of this waste in landfills.

2. MATERIAL AND METHODS

The work was developed from the incorporation WTPS in different proportions in the substrate for planting seedlings of native species to the Atlantic forest. Thus, the development of the seedlings produced with this mixture (WTPS + substrate) was evaluated in relation to survival rate, stem height, stem diameter and Dickson Quality Index. Finally, there were evaluated the economic and environmental benefits in relation to the reduction of consumption of natural resources, increase in the life of the landfill, as well as destination of the generated waste.

The sludge used in the experiment comes from WTP Porto das Caixas, operated by State Company of Waters and Sewers of Rio de Janeiro (CEDAE in portuguese), located in the municipality of Itaboraí. As can be seen from Figure 01, the municipality of Itaboraí is part of the Metropolitan Region of Rio de Janeiro, one of the main Brazilian metropolises and inserted in the southeastern region of the country.

Figure 01 –Location of WTP Porto das Caixas in the municipality of Itaboraí, Metropolitan Region of Rio de Janeiro.

The Porto das Caixas WTP is of the conventional type with complete treatment cycle. The raw water is captured in the Macacu River and due to its characteristics there is no need for pH correction. Its total treatment capacity is 260 L/s, and it consists of six decanters and fourteen sand filters. Aluminum sulfate ($Al_2 (SO_4)_3$) is used as the coagulant for the physical-chemical treatment.

The decanted sludge has a solid content of less than 1% and to be destined to the landfill it must be above 30%. Thus, it is send to the treatment of the solid phase composed of concentrator and a mechanical dewatering by centrifuges. The monthly production of sludge in WTP Porto das Caixas is approximately 15 m³ that are destined to the sanitary landfill. The amount charged for disposal of the sludge in the landfill is approximately US$ 7.00 per cubic meter. Figure 02 shows the texture of the centrifuged sludge from the Porto das Caixas ETA, with solids content higher than 30% and that was used in the experiment.

Figure 02 – Centrifuged sludge from WTP Porto das Caixas with solids content higher than 30%.

The CEDAE has a socio-environmental program that aims at the reforestation of degraded areas in the catchments where it captures water for supply. The company currently has five nurseries that have a production capacity of 1.8 million seedlings per year of species native to the Atlantic Forest. Thus, for the development of the study part of the sludge produced in the centrifuges in the month of June of 2017 was sent to one of those forests nursery located in the municipality of Magé and there it remained in a containment basin protected from weathering for three days.

This forest nursery, the first one inserted inside a prison unit in the state of Rio de Janeiro, is located 25 km from the municipality of Itaboraí and is located in the Agricultural Criminal Colony of Magé. With more than 30.000 m², the nursery has a production capacity of 1.2 million annual seedlings, being among the largest producers of native forest seedlings in the state. In the nursery, there are produced more than 200 species native to the Atlantic Forest.

One of the species found in the Atlantic Forest is the Schinus terenbinthifolius, commonly known as Aroeira Pimenteira. The Aroeira Pimenteira is a species belonging to the family Anacardiaceae. According to Lorenzi (1988), it is considered a small to medium-sized plant, with fast growth and relatively short cycle, heliophile and pioneer. Eventually, it can be found in clearings and forest edges, but usually colonize open areas, especially riverbanks and alluvial soils, supporting flooding and waterlogging of the soil.

This species is commonly used for forest recovery because of its rapid growth and its ability to adapt to various types of soil. Due to this characteristic, this species was used in the experiment. There were used 192 seedlings of Aroreira Pimenteira; the seedlings were collected in the nursery located in the forest nursery itself.

The nurseries use various wastes generated in the operational sectors of the company, aiming at the economy in obtaining inputs and environmental improvement. One of the wastes used in the nurseries is the Sewage Sludge – SS. Abreu (2014) has confirmed that SS can be used as a substrate for the production of flower seedlings, favoring the growth and nutrition of the plants, which are produced without the need for application of chemical fertilizers.

For the production of seedlings, the nursery uses an average of 15,000 m³ of substrate per year, with 7,500m³ of SS and 7,500m³ of a commercial clay soil. The average cost of commercial soil used in the state of Rio de Janeiro is R$ 10,00 per cubic meter. As one of the objectives of the study is the reduction of the use of natural resources and the decrease of costs by the acquisition of input, the commercial soil was only used as a control treatment in this experiment..

According to the whole context presented, the study was developed in three stages:

- Stage 01 – Preparation of substrates
- Stage 02 – Replication and Analysis of the seedlings
- Stage 03 – Environmental and economic analysis of the incorporation of RETA in the substrate

STAGE 01 – Preparation of substrates

To evaluate the potential of the use of WTPS in the production of the seedlings of Schinus terenbinthifolius, (Aroeira Pimenteira), 6 different ratios were adopted between WTPS, SS and commercial soil, named traits (T1, T2, T3, T4, T5 and T6), as shown in Table 01. It should be emphasized that the first trait, called "control" (T1), corresponds to the trait that is currently used in the nursery, composed of commercial soil and SS. Also, for each trait 4 replicates were performed with 8 samples of the seedlings.

Table 01 – Traits used to prepare the substrate

Substrate	T1	T2	T3	T4	T5	T6
WTPS	0%	100%	75%	50%	25%	0%
SS	50%	0%	25%	50%	75%	100%
Commercial Soil	50%	0%	0%	0%	0%	0%

To prepare the samples there were used 14L buckets to cube the volume of the substrates, a mixer to mix the substrates, handcart to transport the substrates, as well as tools such as shovel and spatula. The samples were prepared in the storage area of the substrates as shown in Figure 03. After separating the quantities of each trait, the substrates were mixed in a concrete mixer to form the mass and soon after they were sent to the bench where they were placed manually in bags specific for the replicate of the seedlings.

Figure 03 – Mix (WTPS + SS + commercial soil) samples prepared.

STAGE 02 – Replication and Analysis of the seedlings

The bags with the blends of each trait were transported to a nursery reserved for the experiment in the shaded area of the nursery. Manual holes were made in the bags for root placement. The holes were then capped with the substrate itself, leaving the stem of the seedlings out of the bags. The seedlings were then arranged in the area reserved for the experiment separated by repetition as shown in Figure 04.

Figure 04 – Disposition of the seedlings in the area reserved for the experiment

The experiment took place from June to December of 2017 with 6 total measurements, with a difference of 21 days between them:

- Survival rate from the number of surviving seedlings in the analyzed period;
- Growth rate from the measurement of seedling height and diameter of the stem;
- Dickson Quality Index from root and stem sample weighing.

The **survival rate** was calculated for each trace and for the total seedlings of the experiment. Thus, the number of surviving seedlings was measured in the experiment, considering dead seedlings the ones that completely defoliated and those whose leaves appeared to be dry. The survival rate calculation is described by Equation 1, where the Survival Rate (S), expressed in percentage (%),is equal to the total amount of surviving seedlings (n) divided by the total number of seedlings analyzed (Mt).

$$S = \left[\left(\frac{n}{M_t}\right) x100\right]$$

Equation 01 : Survival Rate

Where:

S = Survival Rate [%]

n = Number of surviving seedlings [un]

M_t = Total number of seedlings analyzed [un]

The **growth rate** was calculated from the height of the seedlings and the diameter of the stem. For measuring the seedlings' height, a graduated metric ruler with an accuracy of 0.05 cm was used, considering the height of the seedling from the ground surface to the maximum point of its crown. The diameter of the stem was measured with a manual pachymeter with a precision of 0.05cm. As the diameter of the stem in the first two measurements was too thin to measure, the data were collected only from the 3rd measurement, ie with 63 days from the beginning experiment. Thus, the growth rate, measured in percentage (%), was calculated by Equations 02 and 03, which respectively relate height of the seedlings x measurement time and stem diameter x measurement time.

$$T_h = \frac{H}{t}$$

Equation 02: Growth rate in relation to the seedlings height

$$T_{cd} = \frac{D_c}{t}$$

Equation 03 : Growth Rate in relation to the stem diameters

Where:

T_h = Growth rate in relation to the seedlings height [cm/day]

T_{cd} = Growth Rate in relation to the stem diameters [cm/day]

H = Seedlings hight [cm]

t = Measurement time [day]

Dc = Diameter of the stem [cm]

Finally, the **Dickson Quality Index** (DQI), developed by Dickson (1996) is a balanced formula of the various morphological parameters considered important for seedling analysis. Fonseca et al. (2002) considered the index to be a good indicator of the quality of the seedlings since the calculations consider the robustness and the balance of the biomass distribution of the seedlings. Thus, for the calculation of DQI (Equation 04) there were considered the height of the seedlings, the diameter of the stem and the weight of the total dry matter, dry matter of the aerial part and dry matter of the root part.

$$DQI = \frac{PMST}{(\frac{H}{D_c}) + (\frac{PMSPA}{PMSR})}$$

Equation 04: Dickson Quality Index

Where:

DQI = Dickson Quality Index

H = Seedlings hight [cm]

D_c = Diameter of the stem [cm]

PMST = Weight of The Total Dry Matter [g]

PMSPA = Weight of the Dry Matter of The Aerial Part [g]

PMSR = Weight of the Dry Matter of The Root Part [g]

In order to measure the weight of the dry matter, the average height of the seedlings in the last measurement was calculated, and in all replicates, the four seedlings closest to the average height were selected for measurement. The aerial part (stem and leaves) was separated from the roots, dried in a greenhouse for 24 hours and afterward, the averages were calculated for each trace. To calculate the height/diameter ratio of the stem (H/Dc) the average height (H) and diameter (Dc) values of each trait in the last measurement were used.

STAGE 03 – Environmental and economic analysis of the incorporation of WTPS in the substrate

For the development of the environmental and economic analysis of the incorporation of WTPS in the substrate, it was used data of the trait that presented the best result in relation to the variables described previously in Stage 02. Thus, the economic estimate was based on the cost avoided by the company, related to the purchase of the commercial soil and related to the disposition of the volume of WTPS in the landfill. And in the environmental analysis, the discussion was based on the volume of soil that was no longer withdrawn from the environment. It should be noted that for the economic estimation, average values were adopted in the state of Rio de Janeiro, both for the volume of the commercial soil and for the disposal tariff in the sanitary landfill. Also, transportation costs will not be measured in this work.

Equations 05, 06, 07 and 08 were used in the calculations of this stage and address respectively: the volume of waste not disposed in the landfill; cost avoided by the acquisition of commercial land; cost avoided by the WTPS disposal in the landfill; and total cost avoided by the sanitation company.

$$V_d = \%T x V_t$$

Equation 05: Volume of waste not disposed in landfill

Where:

%T= Percentage of WTPS in the best treatment

Vt = Total volume used in the nursery per year [m³/year]

$$C_s = V_s x R_s$$

Equation 06: Avoided cost by commercial soil acquisition

Where:

V_s = Volume of soil not removed from natural resources [m³/year];

R_s = Cost of soil practiced in the state of Rio de Janeiro [R$/year]

$$C_d = V_d x R_d$$

Equation 07: Avoided cost by disposal of WTPS in landfill

Where:

V_d = Volume of waste not disposed in landfill [m³/year];

R_d = Cost of the disposal of WTPS in landfill practiced in the state of Rio de Janeiro [R$/year]

$$C_t = C_s + C_d$$

Equation 08: Total cost avoided by the water and sewage company

Where:

C_s = Avoided cost by commercial soil acquisition [R$/year]

C_d = Avoided cost by disposal of WTPS in landfill [R$/year]

3. RESULTS AND DISCUSSION

The results will be presented in relation to the variables described in Stage 02 (survival rate, growth rate and Dickson Quality Index) and in relation to the environmental and economic analysis of the incorporation of WTPS in the substrate.

Survival Rate

The seeds of the seedlings have enough nutrients for the seedlings to germinate and grow until the moment of their replication. But after replication, the seedlings need nutrients, sunlight, and water to survive. In nature the roots absorb the nutrients from the soil; therefore the quality of the substrate is very important for the survival of the seedlings. Analyzing the survival rate of the seedlings is essential to verify the quality of the experiment. The mortality of seedlings can occur due to several factors, such as insufficient sunlight, insufficient or excess quantity of water, nutrient deficiency or the presence of some toxic pesticides in the soil. Table 2 shows the number of seedlings in each trait and the number of surviving seedlings, as well as the survival rate.

Table 02 – Results of the analysis of the survival rates of seedlings for each trait

Trait	Analyzed Seedlings (Mt) [un]	Surviving Seedlings (n) [un]	Survival Rate (S) [%]
T1	32	32	100,00
T2	32	26	81,25
T3	32	31	96,88
T4	32	31	96,88
T5	32	32	100,00
T6	32	32	100,00
Total	192	184	95,86

It is possible to verify that there is a high survival rate of all the seedlings in the traces used. However, there was a higher mortality in trait 2 (T2), which has 100% WTPS. This is due to the fact that the WTPS has a low concentration of organic matter in relation to SS, and therefore it does not contain enough nutrients for the seedlings growth. However, the other traits (T1, T3, T4, T5, and T6) that have WTPS in their composition were within the expected analyzes.

Growth Rate

Carneiro (1995) highlighted the importance of the seedlings hight and stem diameter in plant survival and development after field planting. Depending on the characteristics of the species to be cultivated, there may be a growth limit in the nurseries, which would lead to unsatisfactory growth in the field, but it is not the case of *Schinus terenbinthifolius* (Aroeira Pimenteira).

The average height of the seedlings (H) and stem diameters (Dc) collected in the 6 measurements are described in Table 3 and the calculation of the growth rates in relation to height (Th) and in relation to stem diameter (Tdc) are described in Table 4 and represented in the charts of Figures 05 and 06.

Table 03 – Results of analysis of survival rates of seedlings for each trait

Trait	21 days		42 days		63 days		84 days		105 days		126 days	
	H	**D_c**	**H**	**D_c**	**H**	**D_c**	**H**	**D_c**	**H**	**D_c**	**H**	**D_c**
average T1	4,77	-	7,42	-	13,86	0,21	31,16	0,32	49,87	0,45	68,58	0,58
averageT2	4,48	-	4,96	-	4,65	0,12	7,47	0,16	10,22	0,19	13,47	0,20
average T3	4,51	-	5,43	-	6,97	0,14	14,99	0,20	26,77	0,26	38,55	0,33
averageT4	4,73	-	5,86	-	8,22	0,14	20,34	0,22	35,21	0,30	50,08	0,33
averageT5	4,88	-	7,59	-	16,55	0,21	35,67	0,47	55,47	0,54	65,27	0,61
average T6	4,58	-	7,44	-	18,02	0,19	31,83	0,29	50,04	0,40	68,25	0,51

Note: Measurements in centimeters

Table 04 – Growth Rates in relation to seedling height and stem diameter

Trait	**TC in relation to height**						**TC in relation to stem diameter**				
	21-42	**42-63**	**63-84**	**84-105**	**105-126**	**Av.**	**42-63**	**63-84**	**84-105**	**105-126**	**Av.**
T1	0,13	0,31	0,82	0,89	0,89	0,61	0,010	0,005	0,006	0,006	0,006
T2	0,02	0,01	0,11	0,13	0,15	0,09	0,006	0,002	0,001	0,001	0,002
T3	0,04	0,07	0,38	0,56	0,56	0,32	0,007	0,003	0,003	0,003	0,003
T4	0,05	0,11	0,58	0,71	0,71	0,43	0,007	0,004	0,003	0,002	0,003
T5	0,13	0,43	0,91	0,94	0,94	0,67	0,010	0,009	0,006	0,005	0,006
T6	0,14	0,50	0,66	0,87	0,87	0,61	0,009	0,005	0,005	0,005	0,005

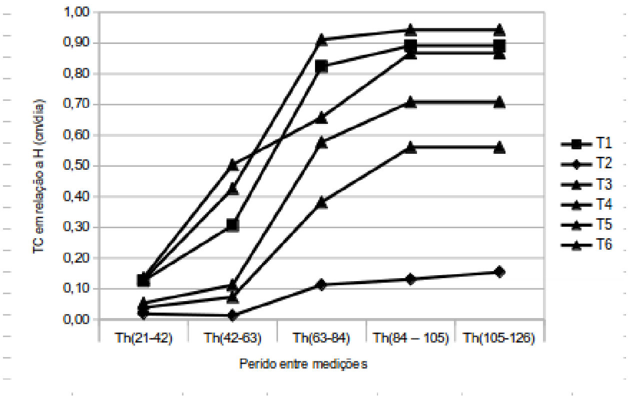

Figure 05 – Growth Rate in relation to the height of the seedlings

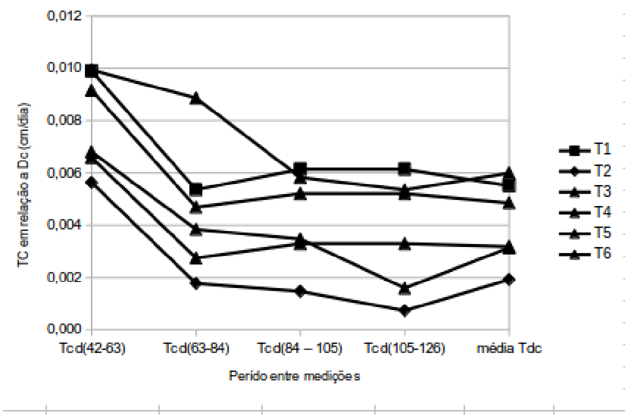

Figure 06 – Growth Rate in relation to the diameter of the stem

It is shown in Table 03 that in the first measurement there is little difference between the heights of each trait, however it can be seen that at the end of the experiment T1, T5 and T6 have the highest heights and T2 the smaller height, the same can be said for the diameter of the stem.

The growth rate varies according to the trace used. In relation to the height, traits T1, T5 and T6 have a high growth rate in the first measurements and after that, they become more constant. The traits T2, T3, and T4 also have the same characteristic, but with a much lower average growth, especially T2. The averages of the growth rates in relation to stem diameter are also much higher in T1, T5 and T6 than in the other traits.

Dickson Quality Index (DQI)

According to Gomes (2001), the higher the value obtained by DQI, the better the quality standard of the seedlings. This shows that the species cultivated with this dosage would present higher productivity in the field than the others. The Figure 07 depicted the Dickson Quality Index. The T1, T5 and T6 traits presented DQI above 0.3. The trait T5, which has 25% of WTPS and 75% of SS was the trait that presented the highest DQI in relation to the other analyzes of the seedlings.

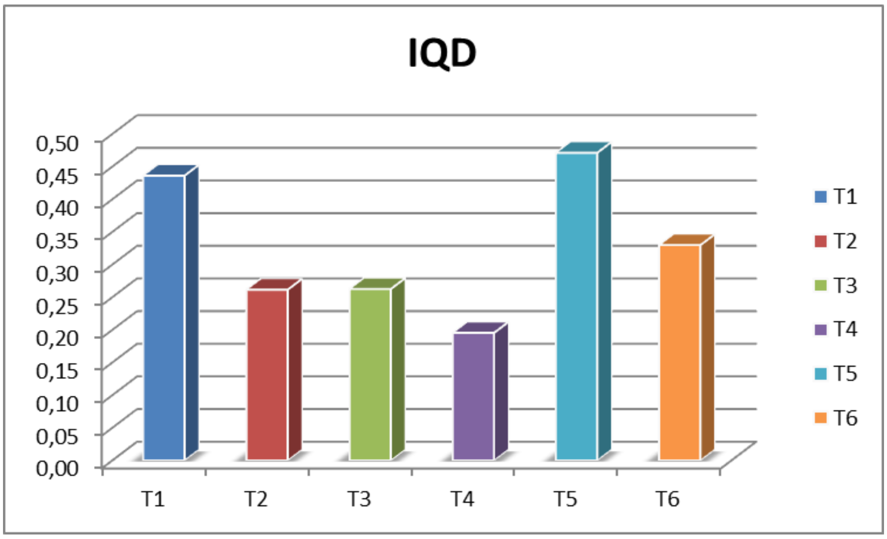

Figure 07 – Dickson Quality Index (DQI) Chart for the Different Traits

The traits T1, T5, and T6 are the traits that presented the best quality index, T5 with the highest result. The traits T2, T3, and T4 were the ones that presented the lowest quality index. Therefore, the T5 Treatment, which has 25% WTPS and 75% SS, was the treatment that presented the best results in the seedling analysis.

Environmental and Economic Analysis of the Incorporation of WTPS in the substrate.

The economic and environmental analysis of the incorporation of WTPS in the substrate for the production of Atlantic Forest seedlings is fundamental when aiming at reuse or recycling or generation. Table 05 presents the results of the estimated calculations of the variables involved in the environmental and economic analyzes.

Table 05 – Economic and environmental analysis calculations

Soil Volume	**Disposal Volume**	**Soil Value**	**Commercial Soil Cost**	**Disposal Value per m^3**	**Disposal Cost**	Avoided Total Cost
[m³/year]	**[m³/year]**	**[US$/year]**	**[US$/year]**	**[US$/year]**	**[US$/year]**	**[US$/year]**
7,500	3,750	3.00	21,400.00	7.00	26,250.00	47,650.00

Substrate consumption in the landfill per year is 15,000 m³, as clay soil currently makes up 50% of the substrate, the commercial soil volume used is 7,500 m³ per year. In the State of Rio de Janeiro, the value of the soil is US$ 3.00 per cubic meter.

Considering the traits that use WTPS in its composition (T2, T3, T4, and T5) it was verified that T5 that has 25% of WTPS and 75% SS is the trait that presented better results, so the amount of sludge used per year in the nurseries is 3,750 m³. The value practiced in the state of Rio de Janeiro for disposal of WTPS in a landfill is US$7.00 per cubic meter.

As the water and sewage company is responsible for allocating the WTPS of Porto das Caixas and for acquiring the clay soil, the avoided cost in case of the replacement of the commercial soil by RWTP is almost US$ 48,000.00 per year.

In addition to the avoided costs, this replacement is very beneficial to the environment since it would no longer annually consume 7,500 m³ of a finite natural non-renewable resource and would increase the useful life of the landfill because it would not land 3,750 m³ of waste per year.

4. CONCLUSIONS

It was possible to analyze that the WTPS can be incorporated into the substrate for native Atlantic Forest seedlings production since survival rate was considered high in all treatments. The traits that best-obtained results in relation to the growth rates were T1, T6, and T5, whereas the T2, T3, and T4 traits obtained the worse results. In relation to the Dickson Quality Index (DQI), T1, T6 and T5 obtained higher indices and T2, T3 and T4 traits the worst. That is, the traits that best obtained results were the traits that had more than 50% of SS in and less than 25% of WTPS in its composition.

Analyzing the results, the trait of the substrate is an essential factor for the incorporation of WTPS into the substrate for the production of forest seedlings. Thus, the trait that best-obtained results, even equaling or surpassing the results of T1 and T6, was the T5 trait, which uses 25% of WTPS and 75% of SS. The worst trait was T2 using 100% WTPS as a substrate.

Regarding economic issues, it is totally feasible to replace the soil with the WTPS, since the water and sewage company that also owns the nursery would not only save on the cost of the clay soil purchase, but also on the cost of allocating the WTPS to the landfill. The avoided cost in case of the replacement of the commercial soil by RWTP is almost US$ 48,000.00 per year. Regarding environmental preservation issues, this substitution is totally feasible, since, in addition to not sending the waste to the landfill, contributing to the reduction of the life of the landfill, the Company would also stop consuming a natural non-renewable resource (commercial soil).

It should not be forgotten that the company will also be in compliance with the current environmental legislation, which currently prioritizes the reuse of solid waste rather than the final disposal in a landfill.

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