Environmental Engineering and Management Journal
May 2018, Vol.17, No. 5, 1169-1178
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

WATER TREATMENT SLUDGE AS POTENTIAL SOIL AMENDMENT FOR NATIVE PLANTS OF THE BRAZILIAN CERRADO

Paulo Scalize[1], Abner Neto[1], Antonio Albuquerque[2]*

[1]School of Civil Engineering, University Federal of Goiás, Av. Universitária, 1499, sala 7, Setor Universitário,
CEP 74605-220, Goiânia, Goiás, Brazil
[2]Department of Civil Engineering and Architecture, University of Beira Interior, Edificio 2 das Engenharias,
Calcada Fonte do Lameiro, 6201-001 Covilha, Portugal

Abstract

This work evaluates the effect of 5 mixtures of water treatment sludge, soil from the Cerrado region (Brazil) and a commercial substrate on the growth of 4 species of native plants (*Copaifera langsdorffii, Astronium fraxinifolium, Peltophorum dubium* and *Tabebuia roseo-alba*) from the Brazilian Cerrado. A randomized design was setup with four repetitions and WTS loading rates of 0, 204, 417, 638 and 869 g/kg. Plant sampling for analysis was performed at 30, 60, 90, 120 and 150 days after planting, totalling 400 experiments. The results on morphological parameters and foliar analysis showed good results for the sludge loading rates of 204 and 417 g/kg (18,75 and 37,5% of sludge, respectively), for the *Copaifera langsdorffii*, *Astronium fraxinifolium* and *Tabebuia roseo-alba* growth, which presented the highest values for plant diameter, height and total dry matter weight at the 90th and 120th day of experiments. These loading rates seem to provide suitable buffer conditions and nutrients for plant growth. For sludge loading rates of 638 and 869 g/kg the development of all species was reduced, suggesting that plant growth was probably affected by both the higher concentration of Al and the poor mixture structure due to excess of sludge.

Key words: native plants seedlings, sludge rate, sludge reuse, water treatment sludge

Received: September, 2013; Revised final: July, 2014; Accepted: August, 2014; Published in final edited form: May, 2018

1. Introduction

Water treatment plants (WTP) use different technologies for producing potable water. To meet the required treatment standards, WTP need to remove inorganic particles, organic material and pathogens, normally by using lime (CaO or $Ca(OH)_2$), salts of Fe and Al ($Al_2(SO_4)_3.nH_20$, $FeCl_3$ or $Fe_2(SO_4)_3$), long-chain organic polymers and disinfectants, and resulting byproducts (water treatment sludge (WTS)). Alum WTS tend to have a mineral form similar to amorphous $Al(OH)_3$, presenting a large surface area and being highly reactive (Ippolito and Barbarick, 2006).

In the last decades, WTS have been mainly burned, disposed of in surface waters or in landfill sites (Hoornweg et al., 2012). The recent environmental policies of the World Bank, the United Nations and the European Union (EC Directive, 2008; Hoornweg et al., 2012; UNEP, 2005), among others, point out new guidelines for the need to increase the reuse of such waste. The Brazilian and European legislations classify WTS as non-inert solid waste, suggesting that such wastes should be reused or valorised instead of being disposed of, as defined in the EC Directive 2008/98/EC (EC Directive, 2008).

Several studies have already presented results of WTS reused for polishing wastewater treatment (Soares et al., 2012), control of P in eutrophic soils (Agyin-Birikorang et al., 2007; Dayton et al., 2003), recovery of degraded areas (Silva et al., 2005) and agricultural applications (Dayton and Basta, 2001; Oh

---

[*] Author to whom all correspondence should be addressed: e-mail: ajca@ubi.pt; Phone: +351-275-329981; Fax: +351-275-329969

et al., 2010). The potential toxic effect of Al-based WTS has also been studied, although negative effects on plant growth were not reported for concentrations up to 20 g/kg (Heil and Barbarick, 1989; Lin et al., 2010). The Al^{3+} present as $Al(H2O)_6^{3+}$ in acid environments (pH < 4) is the most relevant toxic form to plants, as it can quickly solubilize and is easily uptaken by plants, inhibiting root growth and plant tissue development (Poschenrieder et al., 2008). Although plants are sensitive to toxicity from soluble Al, its most common forms (oxides and aluminosilicates, such as WTS) are harmless to plants (Wang and Kao, 2004), especially if the pH is higher than 5.

There is more concern with the potential deficiency in P, Na, Ca, K and Mg for plant growth when the Al concentration is high at a pH below 5, since it reacts with P to produce precipitates and replaces K, Ca and Mg at the binding sites in the root apoplast, where high concentrations of such ions are needed for high uptake rates (van Scholl et al., 2004). According to Rigby et al. (2013), WTS may be a suitable organic amendment in soils where there is sufficient P for crop growth, or where soils have a poor P sorbing capacity, to prevent over-applications of P resulting in losses by leaching or erosion.

According to Dayton and Basta (2001), WTS present physical and chemical characteristics that make them a potential material for use as soil substrate substitute, since they predominantly contain humic substances and sediments from the raw water, which makes them similar to fine-textured soils. Several studies point out benefits of WTS application in soil physical properties, such as lower bulk density and both higher soil moisture content and greater soil aggregation, which allows the incorporation of organic matter, nutrients and trace minerals, the increase in microbial activity and pH adjustment (Dayton and Basta, 2001; Elliott, 1990; Silva et al., 2005), as well as the increase in soil water holding capacity (Baziramakenga et al., 2001). Such benefits would be important for the Cerrado soils, which by nature are poor in organic matter and nutrients and present an acid pH. Additionally, this potential use would bring environmental and economic benefits, avoiding the disposal of such wastes in water and reducing treatment costs for incineration or landfilling.

The response of plants to sludge application can be studied by analysing morphological parameters such as leaf area, shoot height (H), plant diameter (PD), ratio between the aerial parts and roots, fresh and dry weights of the aerial parts and roots, shoot stiffness and nutritional aspects, as also observed in the studies of Hunt (1990), Dayton and Basta (2001), Bayala et al., (2009), Ho et al., (2010), Russo et al., (2011) and De Lucia et al., (2013). The analysis of these parameters may help understanding the likelihood of survival and growth of seedlings. The quality of a seedling can be evaluated using the Dickson Quality Index (DQI) (Dickson et al., 1960), which may also be related to other parameters such as the H, PD and *phytomass*.

Therefore, the application of WTS for plant growing in a nursery seems to be an alternative way for reusing this waste. The objective of this work was to evaluate the development of seedlings of four native plants (*Copaifera langsdorffii, Astronium fraxinifolium, Peltophorum dubium* and *Tabebuia roseo-alba*) from the Cerrado biome (Goiania, Brazil), cultivated in a nursery with the application of different sludge doses as substrate. The novelty of the work lies in the potential benefit of using WTS for the development of native plants in areas where soils present low organic and nutrient contents and acid pH.

2. Material and methods

2.1. Experimental setup

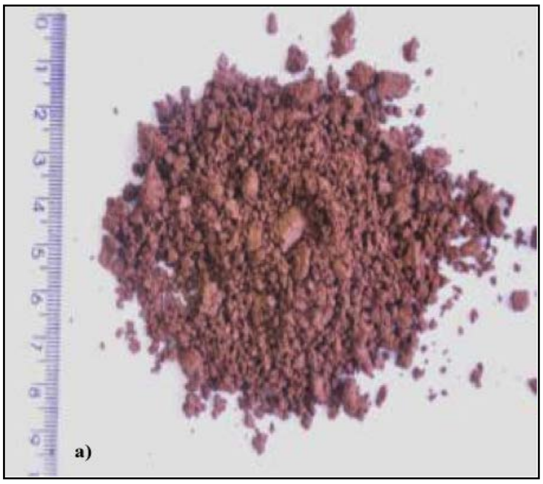
The average physicochemical composition of the sludge was determined by Neto (2011) as follows: pH (6,71), EC (133 µS/cm), organic matter (3.7 g/kg), Al (41.3 g/kg), B (0.037 g/kg), Fe (29 g/kg), P (1.4 g/kg), Mn (1.2 g/kg), Ca (1.4 g/kg), Mg (0.69 g/kg), K (3.5 g/kg) and Na (0.45 g/kg). The average value of Al is within the range reported by other authors, which have used alum sludge for soil amendment (15-170 g/kg) (Agyin-Birikoran et al., 2007; Dayton et al., 2003; Ippolito and Barbarick, 2006; Makris and O'Connor, 2007; Wang et al., 1998). The pH and P concentrations are in the range of values reported for Al-based WTS (6.0–9.2 and 0.4-7.3 g/kg), but the EC is lower than the normal values found in other WTS (350-1670 µS/cm) (Ippolito and Barbarick, 2006; Makris and O'Connor, 2007; Oh et al., 2010; Titshall and Hughes, 2005).

A commercial mixture (Bioplant, produced in Brazil), composed of powdered pine bark, coconut fibre, binders, vermiculite and mineral supplements, was used as substrate. The pH and conductivity of the substrate were 5.2 and 1500 µS/cm, respectively.

The Cerrado soil used in the experiments is classified as red-yellow Oxisol and is considered a sandy-loam soil of medium texture (Neto, 2011). Analysis on soil samples gave average values of pH of 5.5, organic matter of 26 mg/kg and P of 4.3 mg/kg. The clay and sand contents were 400 g/kg and 500 g/kg, respectively. Those values indicate that the soil is slightly acid with a low content of P and a medium content of organic matter.

The weight of the pots ranged from 0.856 kg to 0.928 kg (0.89 kg in average). The substrate content (25%) was kept constant since it is the value used in most of the commercial nurseries in the region. De Lucia et al. (2013) have used 30%, 50% and 70% of compost material with a 30% fixed rate of inert material Those species were selected based on their potential for helping in the recovery of degraded areas in the Cerrado region and also for their high commercial value. The pH and EC of the 5 mixtures were measured at the beginning of the experiments.

The WTS loading rates for each mixture were 0, 204, 417, 638 and 869 g/kg. Ippolito and Barbarick (2006) have used rates between 0 and 1000 g/kg for predicting P availability in soils amended with WTR, Teixeira et al., (2007) have used rates up to 200 g/kg in poor soils for growing grasses and leguminous plants, and Titshall et al. (2007) between 0 and 400 g/kg for growing *Eragrostis tef* (Zucc.), *Cenchrus ciliaris* L., and *Digitaria eriantha*. The percentages of WTS used in T2 to T5 mixtures (18.75%, 37.5%, 56.25% and 75%) are in agreement with the percentages observed in the studies of Oh et al. (2010). The WTS (Fig. 1a) was collected from a sludge pond at a WTP located in Goiânia (Brazil), which uses aluminium sulphate ($Al_2(SO_4)_3$) as the primary coagulant. Five mixtures were tested (T1 to T5) for growing four native plant species (*Copaifera langsdorffii*, *Astronium fraxinifolium*, *Peltophorum dubium* and *Tabebuia roseo-alba*), as shown in Fig. 1b. Four plants of each species (replicates) were cut at 30, 60, 90, 120 and 150 days after planting for analysis, performing 400 experiments (5 mixtures x 4 plant species x 4 replicates x 5 sampling periods).



(a)

(b)

Fig. 1. Set of experiments: a) WTS; b) Set of pots

2.2. Operational conditions

The seeds used in the nursery were collected in areas close to the experimental setup. Seedling lasted from the 5th to the 20th day after sowing and, after this period, the plants were transplanted to plastic bags for experiments. All cultures were grown in a greenhouse with shade cloth (50%), irrigated with sprinklers twice a day and monitored from July to October 2010 (150 days of cultivation). The average temperature in the greenhouse was approximately 20 ºC.

The completely randomized design (CRD) was used for randomly assigning plants to the five mixture conditions, which is commonly used in greenhouse experiments (Agyin-Birikorang et al., 2007; Dayton and Basta, 2001).

The growth conditions and seedling quality were evaluated for the 30, 60, 90, 120 and 150 days after planting through the determination of the survival rate, the evolution of morphological characteristics (PD, H, the *phytomass* of the aerial parts and root parts (green and dry *phytomass*)) and the DQI. The survival rate for each species was determined considering the number of seedlings alive over the total number of seedlings in each mixture.

2.3. Plant analysis

The PD was measured in several points close to the ground, using a caliper, and the average value was registered. The H was measured from the ground to the canopy through a graduated metric ruler. A foliar analysis was carried out at the UFG by determining the contents of Ca, Cu, Fe, K, Mg, Mn, N, P, Pb, S and Zn, following standard methods described by Silva (2009).

The *phytomass* was obtained by evaluating both the fresh weight (green weight) and the dry weight (after drying in an oven) at the end of the experiments. Plant shoots and roots were rinsed in deionised water to remove any adhering particles. Afterwards, the plants were divided into the aerial part (leaves and neck) and root part (roots and rhizomes) and their green weight and dry weight were registered. In order to measure the dry weight for both the aerial part (APDW) and the root part (RPDW), the plants were dried in an oven at 105 °C (model Nova Ética, Brazil) and were weighted several times until they reached a constant weight. The total dry matter weight (TDMW) was obtained from the sum of the APDW and RPDW.

The DQI is a good indicator of seedling quality, because its calculation considers the robustness and balance in the distribution of biomass, considering the results of several important parameters to be used for quality assessment (Hunt, 1990). The DQI was estimated for all the 400 collected samples according to Eq. (1) (Dickson et al., 1960).

$$DQI = (TDMW/((H/PD)+(APDW/RPDW))) \quad (1)$$

2.4. Statistical analysis

The PD and H values obtained for each species were analysed by one-way ANOVA to evaluate the significance of the effect of each mixture (T1 to T5) on species growth. The Tukey test (5% probability of difference between averages) was used to compare each mixture to the growth control. For the preparation and cultivation of seedlings, different doses of Cerrado soil, commercial substrate and WTS were used as shown in Table 1.

3. Results and discussion

3.1. Survival percentage

A soil substitute suitable for plant growth should have a pH from 5 to 8 and EC lower than 4000 µS/cm to avoid the risk of salinization (Dayton and Basta, 2001). In order to be beneficial, a soil substitute should not have excessive concentrations of heavy metals, Ca, Mg, Al and K to avoid phytotoxicity for plants. The pH and EC values of the mixtures (Table 1) indicate that they are not harmful to plant growth. As the sludge loading rate increases, the pH of the mixture also increases and the EC decreases and, therefore, the WTS contributes for buffering the mixtures. The decrease in soil content and the increase in alum sludge, from mixtures T1 to T5, led to the decrease in EC, since the organic contents were reduced. As referred by De Lucia et al., (2013) pH and EC values far from the optimum range for plant growth can seriously compromise their growth, especially the acidophilic and salt-sensitive ones. These results show that WTS can bring a positive effect in controlling EC in soils. The survival rate in the experiment can be considered high for the four plant species (Table 2), ranging from averages of 84% (*Tabebuia roseo-alba*) to 100% (*Peltophorum dubium*).

The results indicate that mixtures with WTS between 18.75% and 75% are not harmful to the *Copaifera langsdorffii*, *Astronium fraxinifolium*, *Peltophorum dubium* and *Tabebuia roseo-alba* species. The largest mortality rate found for *Tabebuia roseo-alba* does not seem to have been related to the mixtures, but to the quality and storage of the seeds. It was also noticed that, after 60 days of culture, no more individuals were found dead. The species that survived until this period lasted until the end of the experiment.

3.2. Evolution of morphological parameters

For determining the increment of PD and H in each of the biometric samples, the absolute average values were considered for each species. It was observed linearity in the growth of the different species for each mixture, showing their progressive development over time. Table 3 shows the results of analysis of variance applied to PD and H for the mixtures with higher significance for each species. Table 4 present the average values for both variables, as well as the results of the Tukey test at 5% probability (marked with a and b). In bold are highlighted the periods of time where more significant differences between averages were observed.

Table 1. Experimental plan

Parameters and plant specie		***T1***	***T2***	***T3***	***T4***	***T5***	***Number of experiments***
		Substrate: 25% Soil: 75% WTS: 0%	Substrate: 25% Soil: 56.25% WTS: 18.75%	Substrate: 25% Soil: 37.50% WTS: 37.50%	Substrate: 25% Soil: 18.75% WTS: 56.25%	Substrate: 25% Soil: 0% WTS: 75%	
Parameters	pH	6.05	6.07	6.24	6.32	6.45	-
	EC (µS/cm)	485	485	424	441	103	-
	WTS loading rate (g/kg)	0	204	417	638	869	-
Plant specie	*Copaifera langsdorffii*	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	100
	Astronium fraxinifolium	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	100
	Peltophorum dubium	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	100
	Tabebuia roseo-alba	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	5 seedlings 4 replicates	100
Total number of plants		80	80	80	80	80	400

Table 2. Percentage of surviving plants for each mixture

Plant specie	***Survival (%)***					***Average***	***Standard deviation***
	T1	***T2***	***T3***	***T4***	***T5***		
Copaifera langsdorffii	100	100	100	95	100	99	2
Astronium fraxinifolium	100	100	95	95	100	98	3
Peltophorum dubium	100	100	100	100	100	100	0
Tabebuia roseo-alba	90	85	75	95	75	84	9

In general, it was observed that, as the WTS content increased, the H values increased more than the PD values, with the best results for mixtures T3 (*Copaifera langsdorffi*) and T4 (*Astronium fraxinifolium and Tabebuia roseo-alba*) taking in account the analysis of variance. Sludge loading rates of 638 and 869 g/kg (mixture T4 and T5, respectively) seem to have had no significant influence in the PD. Regardless of the species used, the contact time seems to have had more influence on the increase of H and PD, with more significant results for contact times over 90 days. Table 5 present the average values for both variables, as well as the results of the Tukey test at 5% probability (marked with a and b). Generally, it seems that mixture T2 leads to best results for the *Astronium fraxinifolium* and *Tabebuia roseo-alba* species for 90 to 120 days, whilst mixture T3 shows best results for *Copaifera langsdorffii* and *Astronium fraxinifolium* species for 90 days. Mixtures T4 and T5 present no significant results for most of experiments.

Table 3. Variance analysis for PD and H in each mixture for 30, 60, 90, 120 and 150 days

FV	*Variance analysis*						*FV*	*Variance analysis*			
	PD	*H*	*PD*	*H*	*PD*	*H*		*PD*	*H*	*PD*	*H*
	30 days		**60 days**		**90 days**			**120 days**		**150 days**	
Copaifera langsdorffii											
Mixtures T3 and T4	0.02^{ns}	0.93^{ns}	0.03^{**}	0.6^{ns}	0.050^{*}	5.24^{ns}	**Mixtures T3 to T5**	0.07^{ns}	6.69^{*}	0.03^{ns}	4.69^{ns}
CV	5.61	7.44	3.51	8.32	4.77	9.61	**CV**	5.28	7.86	6.4	7.86
Astronium fraxinifolium											
Mixtures T1 and T4	0.00^{ns}	0.17^{ns}	0.01^{ns}	0.95^{**}	0.04^{*}	1.60^{ns}	**Mixture T4**	0.07^{ns}	9.70^{ns}	0.19^{*}	7.57^{ns}
CV	5.2	10.19	5.21	5.97	6.8	12.78	**CV**	11.80	19.52	11.43	12.53
Peltophorum dubium											
Mixture T4	0.01^{ns}	0.60^{ns}	0.20^{**}	5.66^{ns}	0.86^{**}	19.89^{**}	**Mixture T4**	2.24^{**}	56.81^{**}	3.33^{**}	42.93^{**}
CV	5.51	11.78	6.50	13.39	7.63	11.87	**CV**	9.79	11.43	10.42	9.72
Tabebuia roseo-alba											
Mixtures T4 and T5	0.01^{ns}	0.11^{ns}	0.02^{ns}	0.91^{*}	0.10^{ns}	2.88^{ns}	**Mixture T4**	0.25^{*}	7.40^{ns}	0.20^{ns}	5.07^{*}
CV	5.40	11.05	6.31	9.33	7.58	15.89	**CV**	9.59	16.85	11.26	10.10

*FV: Variation factor; PD: Plant diameter; H: Height of plant; CV: Variation coefficient; Degrees of freedom (DF): 4** Confidence level of 99%; * confidence level of 95%; ^{ns} without statistical significance*

Table 4. Average values for PD at 30, 60, 90, 120 and 150 days

Mixtures	*PD (mm)*				
	30	*60*	*90*	*120*	*150*
Copaifera langsdorffii					
T1	1.9 a	2.2 a	**2.5 b**	3.0 a	3.3 a
T2	2.0 a	2.3 a	**2.6 ab**	2.9 a	3.2 a
T3	2.1 a	2.4 a	**2.7 a**	3.3 a	3.4 a
T4	2.0 a	2.3 a	**2.7 ab**	3.1 a	3.3 a
T5	2.0 a	2.3 a	**2.6 ab**	3.0 a	3.4 a
Astronium fraxinifolium					
T1	0.9 a	1.2 a	**1.5 a**	1.7 a	2.1 a
T2	0.9 a	1.1 a	**1.3 b**	1.5 a	1.9 a
T3	0.9 a	1.1 a	**1.3 b**	1.4 a	1.7 a
T4	0.9 a	1.1 a	**1.3 ab**	1.6 a	2.1 a
T5	0.9 a	1.1 a	**1.3 b**	1.4 a	1.7 a
Peltophorum dubium					
T1	1.1a	2.3 a	3.9 a	5.0 a	5.7 a
T2	1.1 a	1.9 a	2.8 a	3.5 a	4.0 a
T3	1.1 a	1.9 a	2.9 a	3.6 a	4.1 a
T4	1.1 a	1.9 a	3.5 a	5.0 a	6.0 a
T5	1.0 a	1.6 a	2.9 a	3.9 a	4.6 a
Tabebuia roseo-alba					
T1	1.5 a	2.2 a	2.6 a	**3.1 a**	3.5 a
T2	1.5 a	2.0 a	2.2 a	**2.5 b**	2.9 a
T3	1.5 a	2.1 a	2.3 a	**2.6 ab**	3.1 a
T4	1.6 a	2.1 a	2.5 a	**2.9 ab**	3.4 a
T5	1.6 a	2.2 a	2.5 a	**2.8 ab**	3.2 a

Note: averages followed by the same letters in the columns are not different by the Tukey test ($P < 0.05$). PD: Plant diameter

Although Al toxicity was reported to be more significant for crops grown with a pH below 4 (Poschenrieder et al., 2008), aluminosilicate clays and aluminium hydroxide minerals begin to dissolve when pH drops below 5.5 (Haynes and Mokolobate, 2001; Silva, 2012). As Al availability increased in mixtures T4 and T5, plant roots could have been inhibited due to the reduction of mitotic activity and the inhibition of cell elongation, as reported by Zheng and Yang (2005). Nutrients (P, Na, Ca, Mg and K) availability could also have been reduced when Al was present due to the precipitation of insoluble aluminium phosphates (Haynes and Mokolobate, 2001) and the replacement of cation at the root apoplast (van Scholl et al., 2004). Those circumstances would be responsible for the decrease in plant growth. Another factor that could have inhibited plant growth in the mixtures T4 and T5 was the possible decrease in aeration and water holding capacity, as well as the poor soil structure, due to the presence of excessive WTS (75% of the total weight), which may not have been suitable for proper root development and nutrient uptake.

3.3. Foliar analysis and phytomass variation

The results of the foliar analysis allowed to observe that, in general, as the WTS content increased, the concentration of Ca, K, N, Mg and P in plant shoots decreased. Therefore, the sludge characteristics seem to reduce the plant uptake for these elements, which may be associated to their removal in the sludge due to sorption mechanisms. However, the observed element concentrations are still according to the nutrient content necessary for all species growth (Araujo and Haridasan, 1988). Rigby et al. (2013) have observed an increase in P concentration in P-deficient soils after the application of WTS; however, the foliar analysis has shown that it was not readily available for crop uptake.

There is no significant effect of the five mixtures on the variation of the parameters in the plant tissue for the *Astronium fraxinifolium* species. As far as the heavy metals are concerned, they were not accumulated in the aerial part of the plants, and the observed concentrations are not harmful to plant growth according to the values observed by De Lucia et al., (2013). Therefore, for WTS loading rates up to 869 g/kg there is no evidence of negative influence of the sludge on the concentration of important parameters for the plant tissue of all the native plants (values with significant differences are highlighted at bold).

An ANOVA analysis considering the Tukey test (5%) was carried out on the results (Table 6), and it was observed a small interference of the mixtures on the concentrations of P and Zn in the tissues of *Copaifera langsdorffii*, on the concentrations of N, P and Fe in the tissues of *Peltophorum dubium*, and on the concentrations of Pb, Cu and Zn in the tissues of *Tabebuia roseo-alba*.

Table 5. Average values for H at 30, 60, 90, 120 and 150 days

Mixtures	***H (cm)***				
	30	***60***	***90***	***120***	***150***
Copaifera langsdorffii					
T1	8.6 a	9.4 a	12.0 a	**13.9 b**	16.1 a
T2	9.1 a	10.0 a	13.4 a	**14.6 ab**	15.7 a
T3	9.9 a	10.4 a	14.3 a	**15.5 ab**	16.8 a
T4	8.9 a	10.3 a	13.7 a	**16.2 ab**	17.1 a
T5	8.9 a	10.3 a	15.0 a	**17.2 a**	18.5 a
Astronium fraxinifolium					
T1	4.2 a	5.6 a	6.7 a	10.6 a	15.8 a
T2	3.8 a	4.7 a	6.5 a	10.2 a	14.4 a
T3	3.7 a	4.3 a	6.0 a	9.0 a	12.6 a
T4	4.1 a	4.7 a	7.5 a	13.2 a	14.6 a
T5	3.9 a	4.8 a	6.1 a	10.0 a	12.6 a
Peltophorum dubium					
T1	7.3 a	13.0 a	17.9 a	23.2 a	26.4 a
T2	6.5 a	10.5 a	13.0 a	17.7 a	20.4 a
T3	7.2 a	11.8 a	13.8 a	18.0 a	21.6 a
T4	6.4 a	11.1 a	17.7 a	26.7 a	28.3 a
T5	6.9 a	9.9 a	15.7 a	21.0 a	24.0 a
Tabebuia roseo-alba					
T1	4.6 a	**6.5 a**	8.6 a	11.4 a	**14.2 a**
T2	4.9 a	**5.6 ab**	6.5 a	8.7 a	**11.4 b**
T3	4.6 a	**5.3 b**	7.3 a	9.4 a	**12.7 ab**
T4	4.4 a	**5.4 ab**	8.1 a	11.5 a	**13.1 ab**
T5	4.8 a	**5.8 ab**	7.6 a	10.1 a	**12.4 ab**

Note: averages followed by the same letters in the columns are not different by the Tukey test (P < 0.05). H: Height of plant

The aerial green weight is higher than the root green weight for the *Astronium fraxinifolium* and *Peltophorum dubium* species. An identical trend was observed for the dry weight. According to Neto (2011), the aerial dry weight shows the hardiness of plants and positively correlates with their survival after planting in the field. This would mean that the WTS rates applied in this study are not favourable for all the species as also observed in the studies of Oh et al., (2010) with *Lactuca satuva L.* growing on decomposed granite soils and volcanic ash soils.

Dolgen et al., (2004) observed maximum plant growth (both in shoot and root weights) of iceberg lettuce for a 496 ton/ha sludge application. In three different alkaline soils (clay, calcareous and sandy), a WTS rate of 30 g/kg led to a higher plant dry matter yield of corn (*Zea mays*) without causing P deficiency or Al phytotoxicity (Mahdy et al., 2007). Carneiro (1995) observed that high values for root dry matter are indicators of a high survival rate in the field, since the presence of fibrous roots and rhizomes allows a good development of the plant and the growth of new active roots. It is also important to mention that higher root dry weight values correspond to higher PD, which is another indicator of good quality for seedlings, as also noted by Hunt (1990) and Oh et al., (2010).

The results for the *phytomass* (green and dry weights) of the aerial part and root part, and total dry matter (TDMW) are presented in Table 7. The reduction of green weight in relation to dry weight is presented in Table 8 (this reduction corresponds to a loss of water content).

A low weight reduction indicates that plants may have a good resistance to adverse atmospheric conditions in the field (Carneiro, 1995). Therefore, the *Copaifera langsdorffii* species appear as the ones with better conditions for a good resistance to dry conditions at field scale.

Tabebuia roseo-alba had the highest percentage of reduction in dry weight. It was also observed that, the higher the amount of sludge applied, the lower the percentage of reduction in aerial dry weight and the greater the percentage of reduction in root dry weight. Therefore, the standard seedling quality can vary between plant species and within the same species depending on the growing conditions. Quality standards aim to get references of the characteristics of the plants after planting in the field, highlighting the characteristics that plants can develop in the presence of adverse weather conditions.

The quality parameters can also be influenced by the production techniques, including the characteristics of the containers in which the plants are grown. Thus, the increase in yield and growth may be associated to improvements in soil nutrients and soil structure after WTS addition.

3.4. Variation of DQI

The best DQI values were observed for *Peltophorum dubium* and *Tabebuia roseo-alba* (Fig. 2), which seems to indicate that, for these two species, the quality of seedlings and their productivity will be high.

Table 6. Results of ANOVA for the results of the foliar characterization

Mixtures	***Pb (dag/kg)***	***N (dag/kg)***	***P (dag/kg)***	***K (dag/kg)***	***Mg (dag/kg)***	***S (dag/kg)***	***Cu (dag/kg)***	***Fe (dag/kg)***	***Mn (dag/kg)***	***Zn (dag/kg)***
Copaifera langsdorffii										
T1	0.33 a	1.03 a	**0.52 a**	0.88 a	0.16 a	0.11 a	27.33 a	281.0 a	195.0 a	**22.6 ab**
T2	0.33 a	0.57 a	**0.44 ab**	1.00 a	0.26 a	0.11 a	32.33 a	344.6 a	196.6 a	**21.43 b**
T3	0.36 a	0.63 a	**0.16 b**	0.89 a	0.26 a	0.10 a	29.66 a	485.3 a	164.6 a	**25.5 ab**
T4	0.36 a	0.83 a	**0.23 ab**	0.89 a	0.23 a	0.09 a	43.00 a	492.6 a	186.3 a	**27.2 a**
T5	0.43 a	1.10 a	**0.23 ab**	0.90 a	0.16 a	0.09 a	30.00 a	396.6 a	118.3 a	**27.2 a**
Astronium fraxinifolium										
T1	0.36 a	1.32 a	0.54 a	1.18 a	0.13 a	0.12 a	31.33 a	497.0 a	110.3 a	25.5 a
T2	0.40 a	1.11 a	0.58 a	1.21 a	0.10 a	0.15 a	39.66 a	416.0 a	110.6 a	26.1 a
T3	0.40 a	0.99 a	0.45 a	1.18 a	0.13 a	0.13 a	35.00 a	468.6 a	96.6 a	26.3 a
T4	0.26 a	1.03 a	0.53 a	1.22 a	0.10 a	0.13 a	31.00 a	421.3 a	132.6 a	34.5 a
T5	0.36 a	1.13 a	0.40 a	1.20 a	0.16 a	0.13 a	33.00 a	375.0 a	117.6 a	128.7 a
Peltophorum dubium										
T1	0.30 a	**0.88 ab**	**0.40 ab**	1.04 a	0.36 a	0.09 a	29.00 a	**315.6 ab**	89.6 a	33.1 a
T2	0.30 a	**0.94 a**	**0.42 a**	1.02 a	0.36 a	0.10 a	31.33 a	**333.3 ab**	114.3 a	25.3 a
T3	0.26 a	**0.76 ab**	**0.33 ab**	1.02 a	0.20 a	0.10 a	30.66 a	**341.0 ab**	106.6 a	30.3 a
T4	0.36 a	**0.73 ab**	**0.28 b**	0.97 a	0.23 a	0.08 a	27.00 a	**369.6 a**	102.3 a	25.5 a
T5	0.33 a	**0.59 b**	**0.30 ab**	0.98 a	0.20 a	0.08 a	27.00 a	**264.3 b**	96.0 a	27.7 a
Tabebuia roseo-alba										
T1	**0.45 ab**	0.98 a	0.32 a	1.07 a	0.25 a	0.12 a	**33.33 b**	310.5 a	42.0 a	**31.4 b**
T2	**0.30 b**	0.82 a	0.37 a	1.06 a	0.35 a	0.13 a	**33.33 b**	330.0 a	105.5 a	**27.7 b**
T3	**0.53 a**	0.72 a	0.33 a	1.10 a	0.30 a	0.13 a	**40.00 a**	297.0 a	102.6 a	**24.2 b**
T4	**0.35 ab**	0.82 a	0.38 a	1.06 a	0.45 a	0.12 a	**38.00 a**	311.5 a	55..0 a	**51.8 a**
T5	**0.40 ab**	0.76 a	0.36 a	1.12 a	0.23 a	0.15 a	**40.33 a**	292.6 a	106.0 a	**26.1 b**

Note: averages followed by the same letters in the columns are not different by the Tukey test (P < 0.05). dag/kg: decagram per kilogram

Table 7. Average phytomass results for each species and mixtures

Mixtures	***Green weight (g/plant)***		***Dry weight (g/plant)***		***Percentage of roots (%)***	***TDMW (g)***
	Aerial	***Root***	***Aerial (APDW)***	***Root (RPDW)***		
Copaifera langsdorffii						
T1	2.2	2.3	0.9	0.8	45.6	1.7
T2	1.9	2.4	0.8	0.8	49.4	1.6
T3	1.6	2.5	0.7	0.8	52.0	1.5
T4	2.1	2.6	0.9	0.8	47.2	1.7
T5	2.2	2.8	1.0	0.9	48.7	1.9
Astronium fraxinifolium						
T1	1.9	0.9	0.5	0.2	30.0	0.7
T2	1.4	0.6	0.3	0.2	31.3	0.5
T3	1.1	0.6	0.3	0.1	34.9	0.4
T4	1.6	1.3	0.5	0.3	40.4	0.8
T5	1.0	0.8	0.3	0.2	36.1	0.4
Peltophorum dubium						
T1	8.4	6.4	3.2	1.8	35.5	5.0
T2	4.2	3.0	1.5	0.6	29.3	2.2
T3	4.4	3.2	1.6	0.7	28.7	2.3
T4	11.0	9.6	4.9	2.3	31.6	7.2
T5	5.9	5.2	2.6	1.1	29.2	3.6
Tabebuia roseo-alba						
T1	2.8	3.4	0.7	0.7	51.1	1.4
T2	1.6	1.7	0.4	0.3	41.4	0.7
T3	1.9	2.0	0.5	0.4	41.1	0.9
T4	2.3	4.1	0.7	0.8	54.7	1.5
T5	1.6	2.8	0.4	0.5	51.8	0.9

Table 8. Percentage of reduction of green weight in relation to dry weight

Mixtures	***Weight reduction (%)***							
	Copaifera langsdorffii		***Astronium fraxinifolium***		***Peltophorum dubium***		***Tabebuia roseo-alba***	
	Aerial	***Root***	***Aerial***	***Root***	***Aerial***	***Root***	***Aerial***	***Root***
T1	58.5	67.2	74.5	74.7	61.5	72.2	75.5	78.9
T2	57.1	66.1	75.5	75.0	63.3	78.8	72.7	81.8
T3	56.6	69.4	75.9	74.9	63.4	79.6	72.8	82.0
T4	55.6	67.9	71.3	75.6	55.5	76.6	70.4	79.7
T5	54.9	66.2	71.6	78.6	56.1	79.8	73.7	83.8

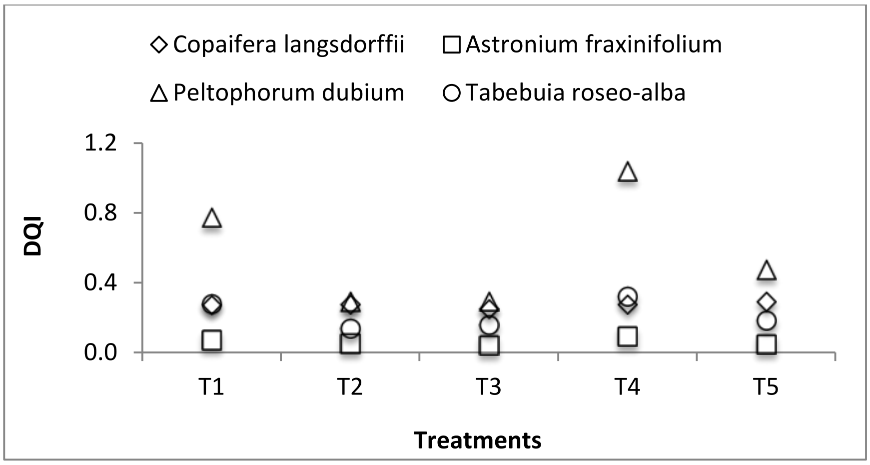


Fig. 2. Variation of the DQI for the different mixtures

The DQI variation for *Copaifera langsdorffii* is linear but with values higher than those observed for the *Astronium fraxinifolium* and *Tabebuia roseo-alba* species. *Astronium fraxinifolium* showed the lowest DQI values and, regardless of the dose of WTS applied, it seems that this species had no difficulty in growing and, therefore, is the one that can have more problems of survival outside the nursery. With the exception of *Peltophorum dubium*, it was observed little variation between the DQI and the applied mixtures and, therefore, the different applied WTS produced similar results. The average DQI values for *Copaifera langsdorffii*, *Peltophorum dubiu*m and *Tabebuia alba-roseo* are higher than the minimum value (0.2) found by several authors (Bayala et al.; Carneiro, 1995, 2009; Hunt, 1990) as ideal to have successful tree seedlings.

Therefore, these results show increasing plant growth and biomass production of all plant species for mixtures T2 and T3. This circumstance seems to indicate favourable pH and salinity conditions, and more suitable contents of organic matter and nutrients (namely P, Na, K, Ca and Mg) for plant growth for sludge loading rates between 204 and 417 g/kg. For higher sludge rates, a lower plant growth was observed, probably due to lower pH values, higher EC values, higher Al concentrations, lower water holding capacity and poorer soil structure, which could have caused growth inhibition of most of species.

4. Conclusions

The results of the experiments seem to indicate that sludge loading rates between 204 and 417 g/kg (mixtures T2 and T3) are suitable for a good development of *Copaifera langsdorffii*, *Astronium fraxinifolium* and *Tabebuia roseo-alba* from the Brazilian Cerrado. These loads seem to provide enough organic matter, nutrients and buffer conditions for plant development.

Higher sludge loading rates are not suitable for plant growth probably due to the higher concentration of Al and the poor mixture holding capacity. Therefore, the use of WTS for seedlings of native plants from the Brazilian Cerrado region seems to be a suitable alternative solution for the final disposal of such wastes.

References

Agyin-Birikorang S., O'Connor G., Jacobs L., Makris K., Brinton S., (2007), Long-term phosphorus immobilization by a drinking water treatment residuals, *Journal of Environmental Quality*, **36**, 316-323.

Araujo G., Haridasan M., (1988), A comparison of the nutrient status of two forests on dystrophic and mesotrophic soils in the cerrado region of central Brazil, *Communications Soil Science and Plant Analysis*, **19**, 1075-1089.

Bayala J., Dianda M., Wilson J., Ouédraogo S., Sanon K., (2009), Predicting field performance of five irrigated tree species using seedling quality assessment in Burkina Faso, West Africa, *New Forests*, **38**, 309-322.

Baziramakenga R., Simard R., (2001), Effect of deinking paper sludge compost on nutrient uptake and yields of snap bean and potatoes grown in rotation, *Compost Science Utilization*, **9**, 115-126.

Carneiro J., (1995), *Production and quality control of forest seedling*, PhD Thesis, Federal University of Paraná, Curitiba, Brazil.

De Lucia B., Vecchietti L., Rinaldi S., Rivera C., Trinchera A., Rea E., (2013), Effect of peat-reduced and peat-free substrates on Rosemary growth, *Journal of Plant Nutrition*, **36**, 863-876.

Dayton E., Basta N., Jakober C., Hattey J., (2003), Using treatment residuals to reduce phosphorus in agricultural runoff, *Journal American Water Works Association*, **95**, 151-158.

Dayton E., Basta N., (2001), Characterization of drinking water treatment residuals for use as a soil substitute, *Water Environment Reserach*, **73**, 52-57.

Dickson A., Leaf A., Hosner J., (1960), Quality appraisal of white spruce and white pine seedling stock in nurseries, *The Forestry Chronicle*, **36**, 10-13.

Dolgen D., Alpaslan M., Delen N., (2004), Use of an agro–industry treatment plant sludge on iceberg lettuce growth, *Ecological Engineering*, **23**, 117-125.

Elliott H., (1990), *Land Application of Water Treatment Sludge: Impact and Management*, American Water Works Association, Denver, USA.

EC Directive, (2008), Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, *Official Journal of the European Union*, L 312/3, 22.11.2008.

Haynes R., Mokolobate M., (2001), Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved, *Nutrient Cycling in Agroecosystems*, **59**, 47-63.

Heil D., Barbarick K., (1989). Water treatment sludge influence on the growth of sorghum-sudangrass, *Journal of Environmental Quality*, **18**, 292-298.

Hoornweg D., Bhada-Tata P., (2012), *What a Waste: A Global Review of Solid Waste Management*, The Worldbank, Urban Development Series, Knowledge Papers no. 15. Washington, USA.

Hunt G., (1990), *Effect of Styroblock Design and Cooper Treatment on Morphology of Conifer Seedlings*, Proc. Combined Meeting of the Western Forest Nursery Associations, Roseburg, USA, 218-222.

Ippolito J., Barbarick K., (2006), Phosphorus extraction methods for water treatment residual - amended soils, *Communications in Soil Science and Plant Analysis*, **37**, 859-870.

Lin Y., Wang D., Shen Y., (2010), Aluminium toxicity in a soil-plant system after paper mill sludge compost application, *Nordic Pulp and Paper Research Journal*, **25**, 244-248.

Mahdy A., Elkhatib E., Fathi N., (2007), Drinking water treatment residuals as an amendment to alkaline soils: Effects on the growth of corn and phosphorus extractability, *International Journal of Environmental Science Technology*, **4**, 489-496.

Neto A., (2011), *Use of water treatment sludge for trees seedling production from the Brazilian Cerrado*, (in Portuguese), MSc Thesis, Federal University of Goiás, Goiânia, Brazil.

Oh T., Nakaji K., Chikushi J., Park S., (2010), Effects of the application of water treatment sludge on growth of lettuce (*Lactuca sativa* L.) and changes in soil properties, *Journal of the Faculty of Agriculture*, **55**, 15-20.

Poschenrieder C., Gunsé B., Corrales I., Barceló J., (2008), A glance into aluminum toxicity and resistance in plants, *Science of Total Environment*, **400**, 356-368.

Rigby H., Pritchard D., Collins D., Walton K., Penney N., (2013), The use of alum sludge to improve cereal production on a nutrient-deficient soil, *Environmental Technology*, **34**, 1359-1368.

Russo G., De Lucia B., Vecchietti L., Rea E., Leone A., (2011), Environmental and agronomical analysis of different compost-based peat-free substrates in potted rosemary, *Acta Horticulturae*, **891**, 265-272.

Silva S., (2012), Aluminium toxicity targets in plants, *Journal of Botany*, **2012**, 1-8.

Silva F., (2009), *Manual on Chemical Analysis for Soils, Plants and Fertilizers*, (in Portuguese), Embrapa Informação Tecnológica, Brasília, Brazil.

Silva E., Melo W., Teixeira A., (2005), Chemical attributes of a degraded soil after application of water treatment sludges, *Scientia Agricola*, **62**, 559-563.

Soares L., Scalize P., Albuquerque A., (2012), *Use of Water Treatment Plant Sludge for the Removal of Total Phosphorous, Nitrate, Turbidity and Color of Effluents from Stabilization Ponds*, Proc. of the Int. AFRICA Sustainable Waste Management Conf., 23-25 July 2012, Lobito, Angola, 6 pp.

Titshall L., Hughes J., (2005), Characterisation of some South African water treatment residues and implications for land application, *Water SA*, **31**, 299-308.

UNEP, (2005), *Solid Waste Management*. Part II, United Nations Environmental Programme, California, USA.

van Scholl L., Keltjens W., Hoffland E., van Breemen N., (2004), Aluminium concentration versus the base cation to aluminium ratio as predictors for aluminium toxicity in *Pinus sylvestris* and *Picea abies* seedlings, *Forest Ecological Management*, **195**, 301-309.

Wang F., Couillard D., Auclair J., Campbell P., (1998), Effects of alum-treated waste water sludge on Barley growth, *Water, Air and Soil Pollution*, **108**, 33-49.

Zheng S., Yang J., (2005), Target sites of aluminum phytotoxicity, *Biologia Plantarum*, **49**, 321-331.