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Growth of Populus and Salix Species under Compost Leachate Irrigation

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Abstract. According to the known broad variation in remediation capacity, three plant species were used in the experiment: two fast growing poplar's clones - *Populus deltoides*, *Populus euramericana,* and willows *Salix alba*. *Populus* and *Salix* cuttings were collected from the nursery of the *Populus* Research Center of Safrabasteh in the eastern part of Guilan province at north of Iran. The *Populus* clones were chosen because of their high biomass production capacity and willow- because it is native in Iran. The highest diameter growth rate was exhibited for all three plant species by the 1:1 treatment with an average of 0.26, 0.22 and 0.16 cm in eight months period for *P. euroamericana*, *P. deltoides* and *S. alba*, respectively. Over a period of eight months a higher growth rate of height was observed in (P) and (1:1) treatment for *S. alba* (33.70 and 15.77 cm, respectively) and in (C) treatment for *P. deltoides* (16.51 cm). *P. deltoides* and *S. alba* produced significantly ($p<0.05$) smaller aboveground biomass in (P) treatment compared to all species. *P. deltoides* exhibited greater mean aboveground biomass in the (1:1) treatment compared to other species. There were significant differences ($p<0.05$) in the growth of roots between *P. deltoides*, *P. euramericana* and *S. alba* in all of the treatments.

Key words: Phytoremediation, growth parameters, fast growing, Compost leachate.

Introduction

An important principle of phytoremediation is to match the proper plant species and subspecies to the contaminated site and planned applications. Consideration must be given to soil, microclimate, region, and pests and diseases, as well as the contaminant or mix of contaminants to be cleaned up. Fast-growing tree species have been suggested as appropriate plants for phytoremediation of contaminated water and land because they possess a number of beneficial attributes (JUSTIN *et al.*, 2010). As the species of many fast-growing, short-rotation trees, such as *Salix* sp. and *Populus* sp., are genetically diverse, the opportunity exists to select genotypes resistant to high salt or metal concentrations, or for high or low metal uptake (JUSTIN *et al.*, 2010). Attractive motives for the further research and application of phytoremediation systems are additional ecological benefits such as carbon sequestration, erosion control, reduced pollution, and improved landscape appearance with a high degree of public acceptability (ZALESNY & BAUER, 2007). Additional features that have contributed to the success of such uses include ease of rooting, quick establishment, fast growth, and elevated rates of photosynthesis and water usage (ZALESNY *et al.*, 2008).

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The production of renewable energy sources, also in the form of biomass, has been increasingly proposed in Iran. Providing sufficient plant nutrients (artificial fertilizers) for their optimal growth is of essential importance. At the same time, fertilizers represent an important production cost. Their substitution with waste sources could be a promising option with regards to the reduction of production costs and the simultaneous reduction of spending on the treatment of waste sources like landfill leachate, wastewater from compost production, sludge, etc. (JUSTIN *et al.*, 2010; HOLM & HEINSOO, 2013).

This paper describes a pot experiment with the aim of obtaining data on the response with respect to biomass accumulation two fast-growing poplar clones (*Populus deltoides* and *Populus euramericana*) and a native willows (*Salix alba*) to different concentrations of compost leachate.

Many research papers can be found which investigate the reuse of landfill leachate from old or closed municipal landfill sites with low leachate strength. There is a lack of data on the reuse of high-strength leachate such as wastewater from the production of open windrow compost from green waste and organic municipal wastes, which is the subject of this study.

Materials and Methods

The experiment was performed at the green house of *Populus* Research Center of Safrabasteh, located in the eastern part of Gilan province at north of Iran (37º 19´N, 49º 57´E) during the 2013 growing season. According to the known broad variation in remediation capacity, three plant species were used in the experiment: two fast growing poplar's clones *Populus deltoides*, *Populus euramericana* and willows *Salix alba*. *Populus* and *Salix* cuttings were collected from the nursery of the *Populus* Research Center of Safrabasteh in the eastern part of Guilan province at north of Iran. The *Populus* clones were chosen because of their high biomass production capacity and willow, because it is native in Iran.

At the beginning of the growing season, in mid-March 2013, 20 cm long cuttings were processed from young, 1-year old seedlings of *Populus* and *Salix* trees. Cuttings were planted in pots filled with loamy-sand soil of the vicinity of the area with 40 cm depth. The upper 5 cm of each cutting was left above the substrate. The initial substrate used in the experiment was analysed in the laboratory. Substrate analyses, physical characteristics and the analytical methods applied are listed in Table 1.

Table 1. Soil analyses and physical characteristics of the substrate used in the experiment

Component	Unit	Amount
pH		8.31
EC	mS/cm^{-1}	0.128
C_{org}	%	0.08
N_{tot}	%	0.01
P	mg kg^{-1}	0.69
K	mg kg^{-1}	57.60
Ca	mg kg^{-1}	400
Mg	mg kg^{-1}	24
Soil texture		Loamy sand
sand	%	86
silt	%	5
clay	%	9

Compost leachate was taken from a collection reservoir where leachate from open composting of organic municipal wastes and various gardening and plant wastes had been collected. The site is Compost Plant of Municipal Waste Management of Rasht, North of Iran (37º 10´N, 49º 34´E). Its chemical analyses were performed in the Laboratory of Guilan Department of Environment (Rasht, North of Iran) using approved International standards.

The composition of leachate used in the experiment is presented in Table 2. The leachate was dark brown in color and had a putrid odor. The leachates were stored in a 20 L plastic tank and mixed with tap water to reach the specified degree of dilution. Before each container was filled, chemical analysis of leachate was performed (Table 2).

Table 2. Composition of pure compost leachate

Parameter	Unit	Amount
pH		5.22
EC	mS/cm^{-1}	1.26
N_{tot}	mgL^{-1}	21.384
NO_2	mgL^{-1}	0.08
NO_3	mgL^{-1}	21.3
SO_4	mgL^{-1}	7101
PO_4-P	mgL^{-1}	22.11
Na	mgL^{-1}	310
K	mgL^{-1}	250
Ca	mgL^{-1}	152
Mg	mgL^{-1}	1103
Pb	mgL^{-1}	0.27
Ni	mgL^{-1}	0.342
Cd	mgL^{-1}	0.0047
Cr	mgL^{-1}	Trace
COD	mgL^{-1}	260500
BOD	mgL^{-1}	130000
TSS	mgL^{-1}	3060.6
Turbidity	mgL^{-1}	12500

During the first 8 weeks, the plants were irrigated daily with tap water via hand irrigation. Ten plants of each species were used in the experiment. The experiment started at the mid of May 2013 when three treatments were applied to plants: (C) tap water (control), (P) pure leachate and (1:1) one unit (by volume) of leachate mixed with one units of tap water. The experiment lasted until the beginning of December 2013. The pots containing the plants were placed randomly on the experimental field under a transparent roof to protect them against rain. The plants were irrigated with the respective water mixtures to the water holding capacity of the substrate in the pot (0.5 L per pot) in the first weeks of the experiment. With the growth of the plants, the amount of water, added in a daily irrigation event was adjusted to the plant´s demands. Pure leachate was the leachate without dilution. The tap water for treatment (C) and for the preparation of the water mixtures was used from the public drinking water supply.

The growth of the trees was monitored bi-monthly by diameter and height measurements. Diameter was measured from the sprout-out of the principal shoot and height was measured from the sprout-out of the principal shoot to the base of the apical bud.

Mean rates of growth in diameter and height for each treatment were calculated of the growth phase (bi-monthly duration of the experiment including 8 months) of the individual lines (Fig. 1, 2 and 3).

Plants were divided into two parts: aboveground and root system. Plant roots were separated carefully from the substrate and washed with distilled water. After roots and stems were oven-dried at 60°C for 48 h, the biomass of aboveground and root were measured (NAVARROA *et al*., 2014).

The experimental layout was a completely randomized design containing three plant species with five replicates of each treatment. The data were analyzed using the SPSS 16.0 statistical package. Statistical differences between the treatments of each plant species and the statistical difference between the plant species for each treatment were determined by analysis of variance. Results were considered significant at $p<0.05$. The rate of growth of the trees was shown on graphs of diameter and height against time.

Results

High amounts of mass load of elements are added to plants in the pots. Mass loads of N, P and K were much higher in leachate treatments than soil, but Ca mass load was lower compare to soil. The higher ion concentration of the leachate treatment was also reflected in the higher electrical conductivity (1.26 mS/cm) compared to the soil (0.128 mS/cm). Heavy metals were low in collected leachate.

The highest diameter growth rate was exhibited for all three plant species by the (1:1) treatment with an average of 0.26, 0.22 and 0.16 cm in eight months period for *P. euroamericana*, *P. deltoides* and *S. alba*, respectively (Fig. 1). Over a period of eight months, the higher growth rate of height was observed in (P) and (1:1) treatment for *S. alba* (33.70 and 15.77 cm, respectively) and in (C) treatment for *P. deltoides* (16.51 cm) (Fig. 2). The plants growth stopped in the sixth month for all three species in the (P) treatment. All of the *P. deltoides* and *S. alba* in this treatment died at the end of growth period.

The diameter and height of tree species were significant differences in all treatments ($p<0.05$) (Table 3).

P. deltoides and *S. alba* produced significantly ($p<0.05$) smaller aboveground biomass in (P) treatment compared to all species. *P. deltoides* exhibited greater mean aboveground biomass in the (1:1) treatment compared to other species (Table 4). *P. euramericana* exhibited significantly ($p<0.05$) greater mean aboveground biomass in the (P) and (C) treatments compared to the other species (Table 4).

The results of the total aboveground biomass were separated into two groups: the (C) and (1:1) treatments with greater total aboveground dry mass and the (P) treatment with significantly ($p<0.05$) smaller total aboveground dry mass for all three plant species (Table 4). *P. deltoides* exhibited the greatest mean total aboveground dry mass accumulation in all of the treatments (Fig 3).

The pattern of root dry mass accumulation across treatments was similar to the aboveground mass accumulation, with the greatest mean root dry mass developed in the 1:1 treatment for *S. alba* . *P. deltoids* and *P. euramericana* exhibited greatest mean root dry mass in C treatment. The total values of root *S. alba* dry mass were higher than the *P. deltoides* root dry mass in the 1:1 treatment (Fig. 4). There were significant differences ($p<0.05$) in the growth of roots between *P. deltoides* , *P. euramericana* and *S. alba* in all of the treatments (Fig. 4). *P. deltoides* and *S. alba* exhibited the greatest mean total aboveground dry mass accumulation in all of the treatments (Fig. 4). *P. euramericana* was the plant species with the smallest amounts of root dry mass accumulation (Fig. 4).

Table 3. Probability values from analysis of variance testing of treatment and period on diameter and height trait of three species irrigated with compost leachate during 8 months.

Trait	Source of variation	
	Treatment	Period
Diameter	<0.0001	0.001
Height	<0.0001	<0.0001

Table 4 . Dry mass (g) of trees components for species and treatment.

Species	Treatment	Biomass component (g)	
		Aboveground dry mass	Root dry mass
	P	0	0
P. deltoides	1:1	20.42±4.14	1.14±0.90
	C	15.86±11.38	1.05±0.67
	P	1.42±0	0.44±0
P. euramericana	1:1	0.77±0	0.45±0
	C	29.57±11.85	1.53±0.19
	P	0	0
S. alba	1:1	6.70±2.97	1.44±0.47
	C	13.34±4.59	0.78±0.32

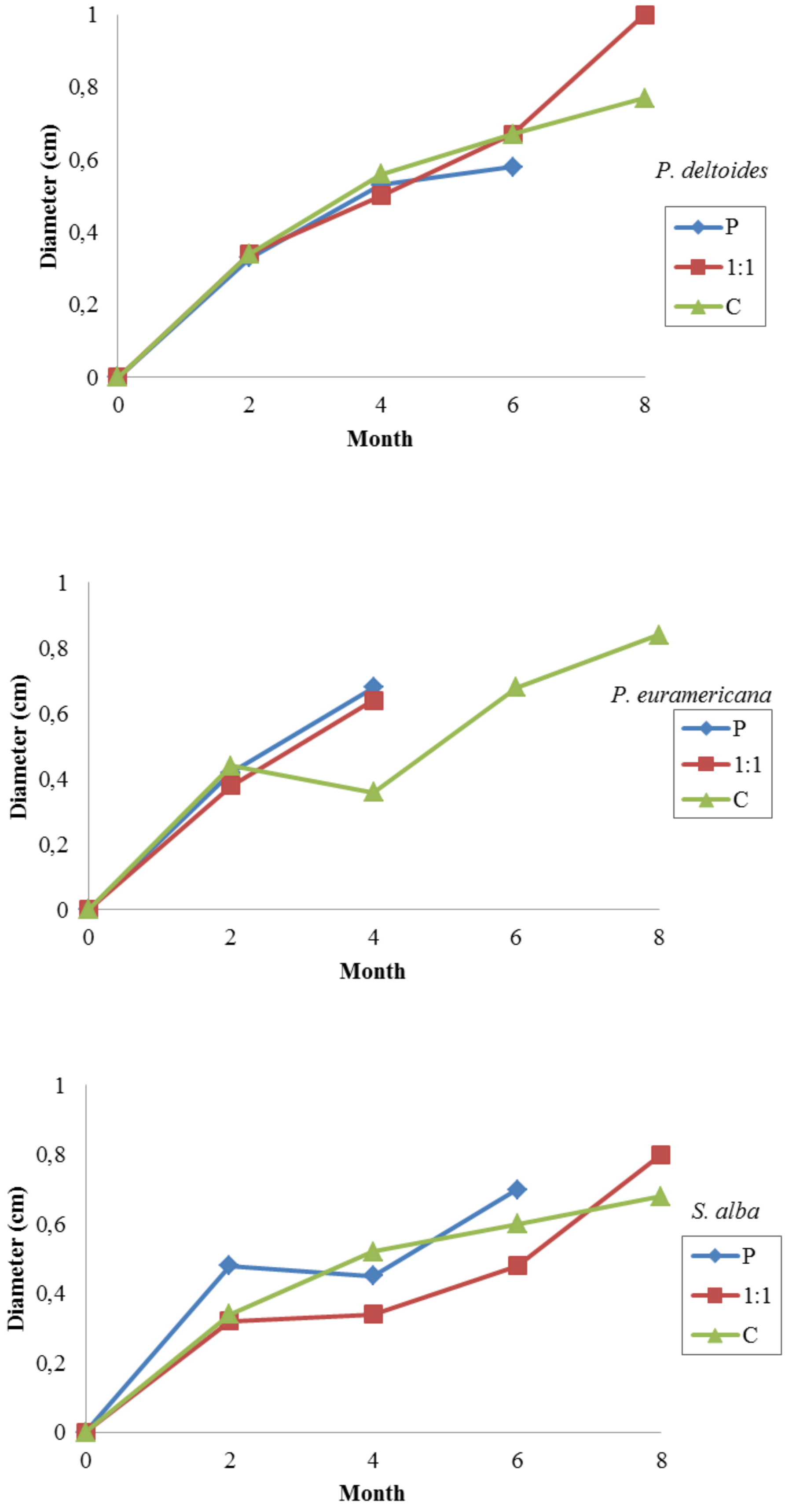

Fig. 1. Mean growth in diameter (cm) of *Populus deltoides*, *Populus euramericana* and *Salix alba* with three concentration of compost leachate.

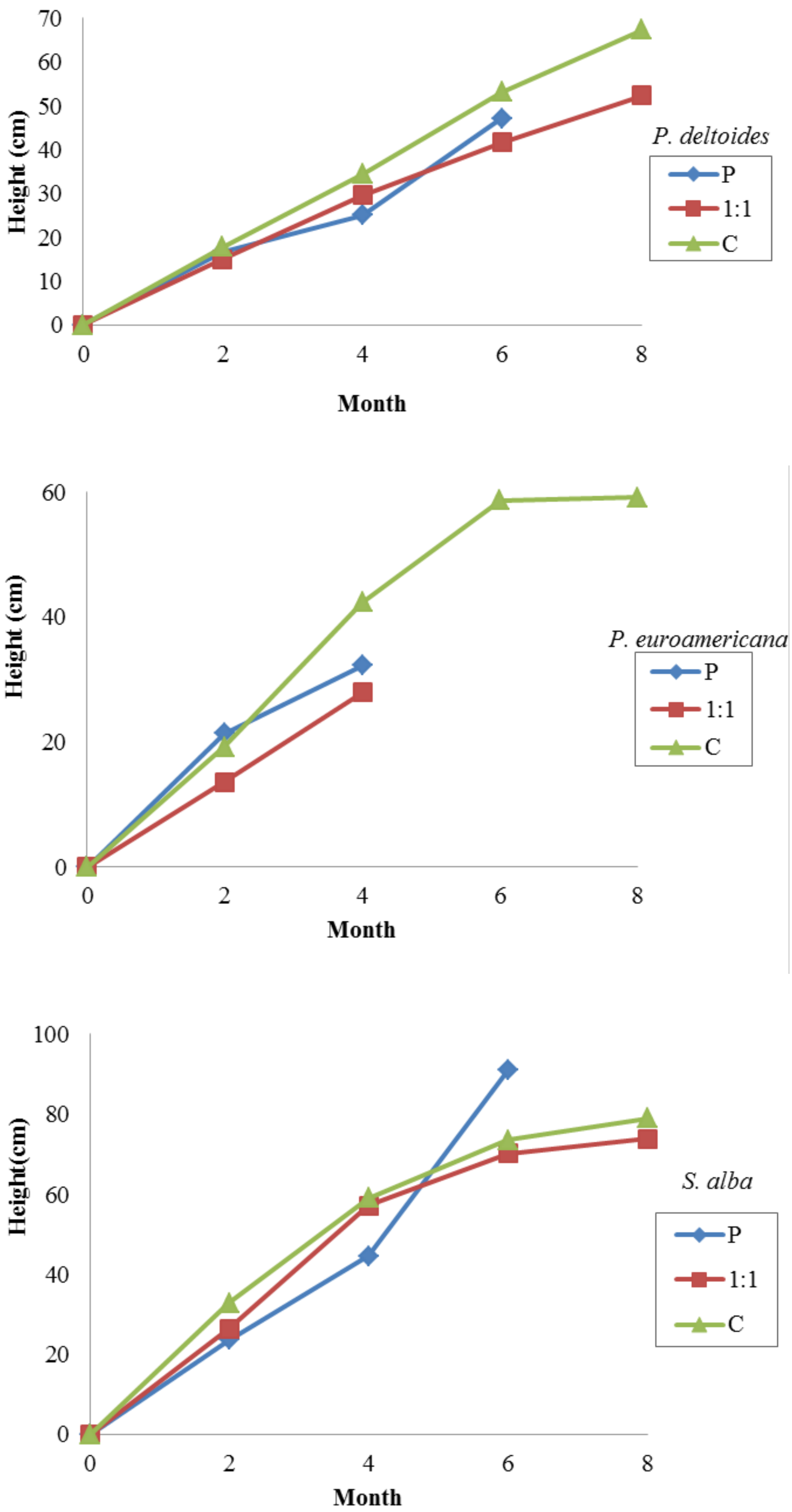

Fig. 2. Mean growth in height (cm) of *Populus deltoides*, *Populus euramericana* and *Salix alba* with three concentration of compost leachate.

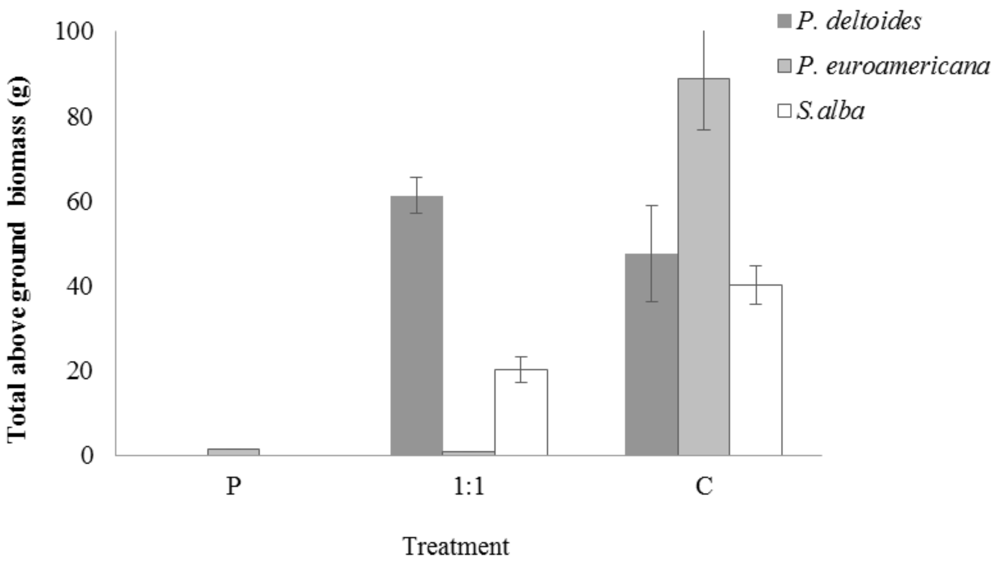

Fig. 3. Comparison of total above ground biomass of three species after 8 months irrigation with pure leachate (P), concentration mixture of leachate (1:1) and tap water (C).

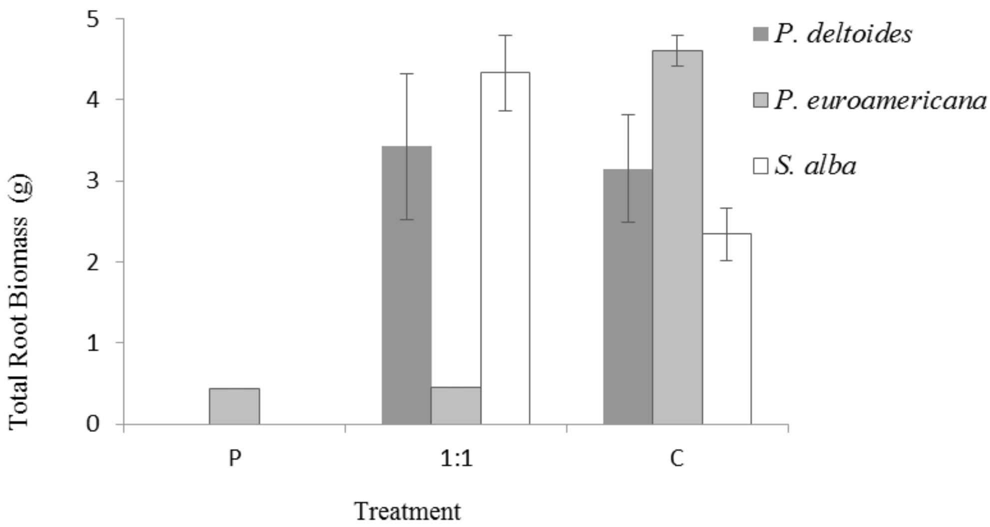

Fig. 4. Comparison of total root biomass of three species after 8 months irrigation with pure leachate (P), concentration mixture of leachate (1:1) and tap water (C).

Discussion

Several studies report positive effects of leachate irrigation on tree growth, showing its fertilizing potential. ZALESNY & BAUER (2007) found that *Salix* clones S287 and S566 exhibited responses favoring leachate irrigation over water. JUSTIN *et al*. (2010) detected the use of landfill leachate treatments resulted a considerably increased aboveground biomass compared to the control tap water treatment. They also found that the growth and biomass accumulation in compost wastewater treatments was reduced compared to tap water and landfill leachate treatments. The use of leachate in (1:1) treatment in our study showed much growth rate and biomass accumulation in tree species.

The concentrations and amounts of wastewater that could be used depend on the constituents of the wastewater and soil, as well as the nutrient demands of the genotypes tested (ZALESNY & BAUER, 2007).

There were statistically significant differences between the aboveground and root biomass in all treatment for all three species. For *P. deltoides* and *S. alba* the higher elemental concentration in the (P) treatment was toxic, indicating that the (P) treatment already had too high concentration of salts and other elements in the water mixture and was toxic to the development of the species.

The compost leachate was a by-product of composting of organic matter, having a low pH (5.22) which is a sign of unfinished degradation processes of raw organic matter due to the inadequate oxygen levels. (P) treatment showed visual signs of stress, with less erect foliage for all three plant species and progressive loss of their lower leaves that leads to damage and died of *P. deltoides* and *S. alba* seedlings. This can be attributed to the combination of high elemental concentrations, imbalance of nutrients, low pH due to the presence of volatile fatty acids and the high salinity of the irrigation leachate. Saline treatments increased root Mg concentration in both aboveground and root biomass (NAVARROA *et al*., 2014).

The application rates of nitrogen were also high in compost leachate. In general agricultural practice it is an acknowledged fact that additional nitrogen is applied to overcome specific toxicity problems and stimulate vegetative growth (AYERS & WESTCOT, 1994).

Reports on significant phytotoxic effect of compost wastewater (addressed as compost liquor) leached from aerobically digested green waste in opened windrow compost piles can be found also from JUSTIN *et al*. (2010) study. The compost wastewater in their measurements had high concentration of BOD_5, ammoniac nitrogen, electrical conductivity and low pH, similar to concentrations in our study. The combined effect of all present components in untreated compost wastewater contributes to phytotoxicity and addresses a need of sufficient pre-treatment, its use only after finished composting process, high dilution, or low mass load of compost wastewater before its use as a plant fertilizer. In addition to the parameters considered, the high concentrations of sulfate (402 mg SO_4/L) in compost wastewater, reported to produce a negative effect on plant growth in water-saturated root zone, should also be underlined (KADLEC & WALLACE, 2009).

However, the negative influence of sulfide toxicity, after the transformation of sulfate in anaerobic environment, on the nutrient uptake of wetland plants was presented. Similar water-saturated environment in the bottom parts of our pots was most probably created also in all compost leachate treatments (7101 mg SO_4/L in our study), where the growth stopped and the water use was significantly reduced, which additionally contributed also to the accumulation of salts.

In addition to ion toxicity, ion imbalances and their interactions (such as Ca^{2+}–Na^{+} and Na^{+}–K^{+}) can also influence plant growth and survival (JUSTIN *et al*., 2010).

FUNG *et al*. (1998) reported that high levels of salt (1.0% NaCl) rapidly reduced the growth of *Populus* and had an immediate effect on predawn leaf water potential, photosynthesis and stomatal resistance. *Populus* has been reported to be sensitive to salt.

It is obvious that pure compost leachate could be treated by land application. However, transferring the experiment to the field would enable leaching of the excess water from the root zone, and the washing-out of salts by precipitation to the lower soil layers and thus better survival with the same amounts of pure compost leachate as used in the pot experiment. The development of above ground biomass is important from the wastewater consumption and phytoremediation point of view (JUSTIN *et al*., 2010). Contaminants may be either sequestered and/or degraded in the leaves and other tissues or be volatilized through leaf stomata and transpired into the atmosphere. In the 1:1 treatment the greatest above ground biomass was developed by *P. deltoides*, while the generated above ground biomass of *S. alba* and *P. euramericana* was respectively after that. *P. deltoides* developed greater aboveground biomass compared to *P. euramericana* and *S. alba*, and this was statistically significant.

ZALESNY & BAUER (2007) selected fast-growing *Populus* and *Salix* clones and their genomic groups after irrigation with landfill leachate during one growing season. In their experiment *Populus* exhibited the greatest diameter and dry mass, and *Salix* exhibited the greatest height and dry mass of root. In our experiment, *S. alba* exhibited the lowest above ground biomass. *P. euramericana* exhibited the greatest diameter growth and grew in all treatment and no high variation was observed. The species survived in pure leachate despite of other two species. The species has succulent and healthy seedlings than two other ones. It was less sensitive to high salinity and acidity than *P. deltoides* and *S. alba*, it indicates the probability of a higher capacity for accumulation of elements like heavy metals.

It is reported, that the greatest phytoremediation levels are not necessary connected with the highest biomass yield (GREGER & LANDBERG, 1999; KLANG-WESTIN & ERIKSSON, 2003; ZALESNY & BAUER, 2007), and that a higher concentration of metals and nutrients is accumulated in the bark than in the wood tissue (PULFORD & DICKINSON, 2005; DIMITRIOU *et al*., 2006; ADLER *et al*., 2008). This should be tested in future elemental analysis of the plant material.

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