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Phytoremediation concept: biomass production and growth of *Populus deltoides* under compost leachate irrigation

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ABSTRACT: Compost leachate is produced by conversion of municipal waste to compost. It contains significant amounts of organic materials, nutrients, soluble salts and small amounts of some heavy metals. Adding compost leachate to the soil can pollute it, and also improve soil fertility. In this study, we investigated absorption and growth performance of *Populus deltoides* under irrigation with leachate of the Compost Plant of Rasht. At the beginning of the growing season, in mid-March 2013, cuttings were processed from young, one-year-old seedlings of *Populus* trees in the greenhouse of the Safrabaste Poplar Research Station. Cuttings were planted in pots filled with loamy-sandy soil in the vicinity of the area with 40cm depth. Compost leachate was taken from a collection reservoir where leachate from the open composting of organic municipal wastes and various gardening and plant wastes had been collected. Five treatments were applied to plants: (C) tap water (control), (P) pure leachate, (3:1) three units (by volume) of leachate mixed with one unit of tap water, (1:1) and (1:3). The growth of tree diameter and height was measured bi-monthly. Aboveground (stem, branches and leaves) and root biomass was inventoried at the end of the growing season. Concentration of elements was determined every three months. Overall, growth parameters in 1:1 and 1:3 treatments were similar together and there were no significant differences between them ($P < 0.05$). Pure treatment had minimum growth because of a high concentration of solvable salts in leachate such as sulphur that causes salinity and high EC in soil. Treatment1:3 exhibited the greatest overall aboveground and root dry mass. Total aboveground dry mass of leachate treatments and water was 202.25 and 47.58 g, respectively.

Keyword: treatment; growth; compost leachate; cutting

Many fast-growing and short-rotation trees such as *Populus* resist to high metal concentrations and contamination (Justin et al. 2010). 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. 2007b). 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 regard 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 of *Populus deltoides* to different concentrations of compost leachate. Several studies report positive effects of leachate irrigation on tree growth, showing its fertilizing potential. Zalesny and Bauer (2007b) found that Salix clones S287 and S566 exhibited responses favouring leachate irrigation over water. Justin et al. (2010) detected that the use of landfill leachate treatments resulted in a considerably increased aboveground biomass compared to the control tap water treatment and the growth and biomass accumulation in compost wastewater treatments were reduced compared to tap water and landfill leachate treatments.

MATERIAL AND METHODS

The experiment was performed in the greenhouse of Safrabaste Poplar Research Station located in the eastern part of Gilan province in the north of Iran (37°19'N, 49°57'E) during the 2013 growing season.

Fast-growing *Populus deltoides* was used in the experiment. *Populus* cuttings were collected from the nursery of the Safrabaste Poplar Research Station. The *Populus* was chosen because of its high biomass production capacity. At the beginning of the growing season, in mid-March 2013, 20 cm long cuttings were processed. Cuttings were planted in pots filled with loamy-sandy soil in the vicinity of the area with 40 cm depth. The upper five cm of each cutting was left above the substrate. The initial substrate used in the experiment was analysed in the soil laboratory.

The determination of the main physical and chemical characteristics of soil was executed according to the standard procedures described by the Soil Science Society of America (Page et al. 1982). Substrate analyses, physical characteristics and the analytical methods applied are listed in Table 1.

Compost leachate was taken from a collection reservoir of leachate belonging to the Compost Plant of Municipal Waste Management of Rasht, North of Iran (37°10'N, 49°34'E). Its chemical analyses were performed in the Laboratory of Guilan Department of Environment (Rasht, North of Iran) using approved Standard Methods for the Examination of Water and Wastewater (Eaton et al. 2005).

The composition of leachate used in the experiment is presented in Table 2. The leachate was dark brown in colour and had a putrid odour. The leachates were stored in a 20 l plastic tank and mixed with tap water to reach the specified degree of dilution. Chemical analysis of leachate was performed before the containers were filled (Table 2).

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

Component	Amount
pH	8.31
EC ($mS\cdot cm^{-1}$)	0.128
C_{org} (%)	0.08
N_{tot} (%)	0.01
P ($mg\cdot kg^{-1}$)	0.69
K ($mg\cdot kg^{-1}$)	57.60
Ca ($mg\cdot kg^{-1}$)	400
Mg ($mg\cdot kg^{-1}$)	24
Soil texture (%)	**loamy sand**
Sand	86
Silt	5
Clay	9

Table 2. Composition of pure compost leachate ($mg\cdot l^{-1}$)

Parameter	Amount
pH	5.22
EC[1]	1.26
N_{tot}	21.384
NO_2	0.08
NO_3	21.3
SO_4	7101
PO_4-P	22.11
Na	310
K	250
Ca	152
Mg	1103
Pb	0.27
Ni	0.342
Cd	0.0047
Cr	trace
COD	2,60,500
BOD	130,000
TSS	3,060.6
Turbidity	12,500

EC[1] – eletrical conductivity in $mS\cdot cm^{-1}$, COD – chemical oxygen demand, BOD – biological oxygen demand, TSS – total suspended solid

During the first eight weeks, the plants were irrigated daily with tap water via hand irrigation. The experiment started in the mid of May when five treatments were applied to plants: (P) pure leachate, (3:1) three units (by volume) of leachate mixed with one unit of tap water, (1:1), (1:3) and (C) tap water (Con-

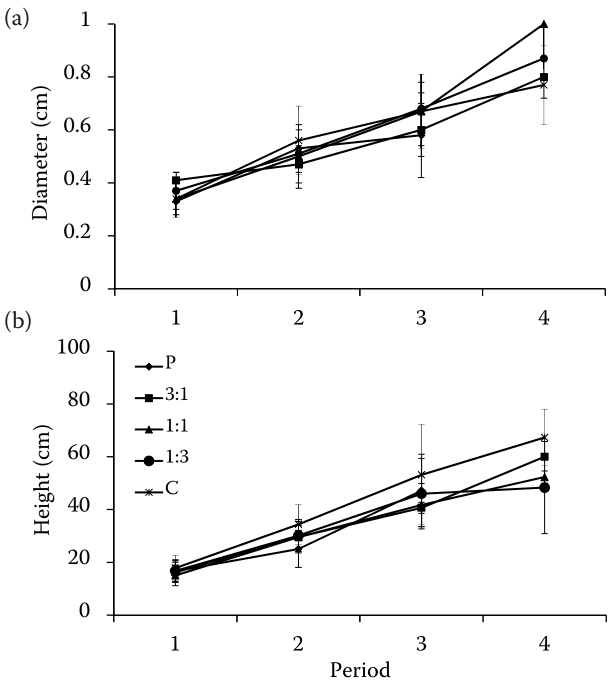

Fig 1. Mean growth in diameter (a) and height (b) of *Populus deltoides* irrigated with five concentration mixtures of compost leachate and tap water

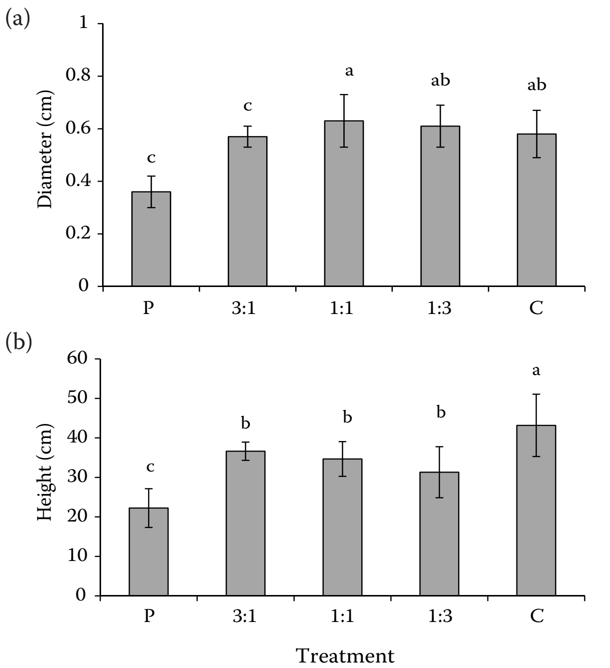

Fig 2. Comparison of mean diameter (a) and height (b) for treatments

trol). The experimental layout was a completely randomized design containing five treatments with ten replicates for each treatment. The experiment lasted until the beginning of December. The pots containing the plants were placed randomly in 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. Pure leachate was the leachate without being diluted. 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.

The diameter was measured from the sprout-out of the principal shoot from the cutting and the height was measured from the ground level to the base of the apical bud on the terminal shoot (Zalesny et al. 2007a).

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

Table 3. Probability values from the analysis of variance testing the main effects of treatment, period and treatment × period

Trait	Source of variation		
	treatment	period	treatment × period
Diameter	< 0.0001	< 0.0001	< 0.0001
Height	< 0.0001	< 0.0001	< 0.0001

All trees were destructively harvested after eight months of growth. The harvested plants were divided into two parts: aboveground part (stem, branches and leaves) and root system. Plant roots were separated carefully from the substrate and washed with distilled water. Then roots and stems were oven-dried at 60°C for 48 h. The biomass of aboveground parts and roots were measured (Navarro et al. 2014).

The data were analyzed using the SPSS 16.0. Statistical differences between the treatments were determined by analysis of variance. The results were considered significant at $P < 0.05$. The rate of tree growth was shown on graphs of diameter and height against time (Fig. 1). Tukey's test was used to obtain differences between level means.

RESULTS

High amounts of mass loads of elements are added to plants in the pots. Mass loads of N, P and K were much higher in leachate treatments than in soil, but the Ca mass load was lower compared to the soil put into the pots. The higher ion concentration of the leachate treatment was also reflected in the higher electrical conductivity (1.26 $mS \cdot cm^{-1}$) compared to the soil (0.128 $mS \cdot cm^{-1}$). Heavy metals were low in collected leachate.

The highest diameter growth rate was exhibited by the 1:1 treatment with an average of 63 cm in an eight-month period. Some plants stopped growth in the sixth month in the P treatment. The highest

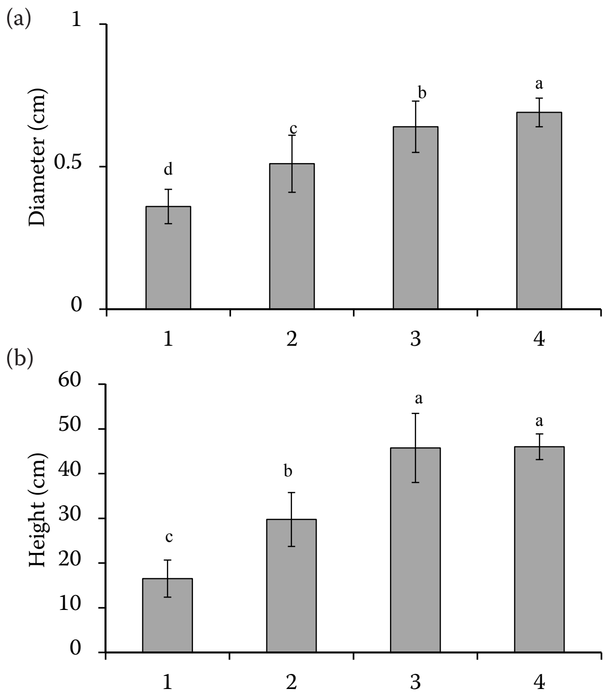

Fig 3. Comparison of mean diameter (a) and height (b) for periods

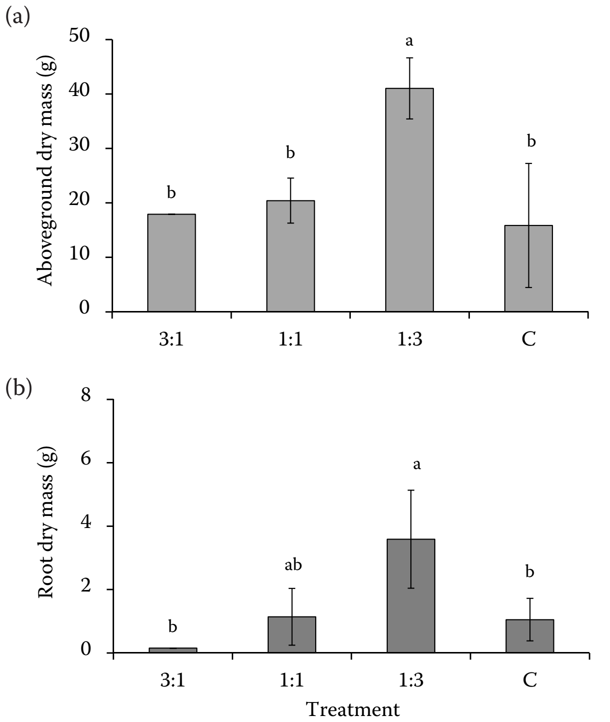

Fig 4. Comparison of mean aboveground (a) and root (b) dry mass components

increment of height (average of 43 cm) was exhibited by the C treatment.

The diameter and height were significantly different in all treatments and periods ($P < 0.05$) (Table 3).

Greater mean aboveground biomass was in the 1:3 treatment, it was significantly greater than in the other treatments ($P < 0.05$). C treatment showed the significantly ($P < 0.05$) smaller total aboveground dry mass for all plants (Fig. 4a).

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 1:3 treatment (Fig. 4b).

DISCUSSION AND CONCLUSION

Several studies reported the positive effects of leachate irrigation on tree growth and showed its fertilizing potential. Justin et al. (2010) detected that the use of landfill leachate treatments increased considerably aboveground biomass compared to the control tap water treatment, but the growth and biomass accumulation in compost wastewater treatments were reduced compared to tap water and landfill leachate treatments.

The concentrations and amounts of leachate that could be used depend on the constituents of the leachate and soil, as well as the nutrient demands of the genotypes tested (Zalesny, Bauer 2007b).

Table 4. Analysis of variance of dry mass components

Trait	Source of variation
Aboveground part	0.005
Root	0.011

There were statistically significant differences between the aboveground and root biomass in all treatments (Table 4). The higher elemental concentration in the P treatment was toxic, indicating that the P treatment already had a too high concentration of salts and other elements in the water mixture and was toxic to the development of the species (Table 2).

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. The comparison of the plant growth in several treatments showed apparently normal and healthy-looking trees, with the exception of P treatment when some trees died.

P treatment showed visual signs of stress, with less erect foliage and progressive loss of lower leaves that leads to damage and 10 seedlings of *P. deltoides* died. 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 the root Mg concentration in both aboveground and root biomass (Navarro et. al 2014).

The application rates of nitrogen were also high in compost leachate. There is an acknowledged fact in general agricultural practice that additional nitrogen is applied to overcome specific toxicity problems and stimulate vegetation growth (Ayers, Westcot 1994).

Kadlec and Wallace (2009) reported that the higher concentrations of sulphate (402 mg $SO_4 \cdot l^{-1}$) in compost leachate had a negative effect on plant growth in the water-saturated root zone and should also be underlined. The concentration of sulphate was 7101 mg $SO_4 \cdot l^{-1}$ in our study, where the growth stopped and the water use was significantly reduced, which additionally contributed also to the accumulation of salts.

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. It has been reported that the *Populus* is sensitive to salt.

It is obvious that pure compost leachate should be treated before land application. However, transferring the experiment to the field would enable the leaching of excess water from the root zone, and the washing-out of salts by precipitation to the lower soil layers, thus better survival with the same amounts of pure compost leachate as used in the pot experiment. The development of aboveground biomass is important from the leachate consumption and phytoremediation point of view (Justin et al. 2010).

We concluded that compost leachate positively affected the growth of *P. deltoids* and increased diameter and height in the periods of measurements due to the fertilization properties of leachate (Fig. 1).

The diameter of trees in P and 3:1 treatments was significantly ($P < 0.05$) lower compared to 1:3 and C treatments (Fig. 2a). The height of trees in P treatment had a significantly ($P < 0.05$) lower increment compared to other treatments. There were no significant differences between 3:1, 1:1 and 1:3 treatments in height (Fig. 2b).

Overall, there were significant differences in diameter growth in the four periods. The final diameter of *P. deltoides* in period 4 was significantly ($P < 0.05$) larger than in the other periods (Fig. 3a), but the height was not significantly different between period 3 and 4 (Fig. 3b).

In the 1:3 treatment the greatest aboveground biomass was developed by *P. deltoides*. There was no statistically significant difference in the development of the aboveground biomass between the 3:1, 1:1 and C treatments for *P. deltoides*, which indicates that leachate irrigation with both mixtures stimulated growth in the same way as irrigation with water. The root dry mass showed the same results as aboveground mass. Total aboveground dry mass of leachate treatments and water was 202.25 g and 47.58 g, respectively.

Zalesny and Bauer (2007b) 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.

The greatest phytoremediation levels are not necessarily connected with the highest biomass yield (Greger, Landberg 1999; Klang-Westin, Eriksson 2003; Zalesny, Bauer 2007b), and 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 the future elemental analysis of the plant material.

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