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Lab-scale phytotreatment of old landfill leachate using different energy crops

Maria Cristina Lavagnolo [a,*], Mario Malagoli [b], Francesco Garbo [a], Alberto Pivato [a], Raffaello Cossu [a]

[a] *Department of Industrial Engineering, University of Padova, via Lungargine Rovetta 8, 35127 Padova, Italy*
[b] *DAFNAE, University of Padova, viale dell'Università 16, 35020 Legnaro, PD, Italy*

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ABSTRACT

Old landfill leachate was treated in lab-scale phytotreatment units using three oleaginous species: sunflower (H), soybean (S) and rapeseed (R). The specific objectives of this study were to identify the effects of plant species combinations with two different soil textures on the reduction of COD, total N (nitrogen) and total P (phosphorous); to identify the correlation between biomass growth and removal efficiency; to assess the potential of oily seeds for the production of biodiesel.

The experimental test was carried out using 20 L volume pots installed in a greenhouse under different leachate percentages in the feeding and subsequent COD, N and P loads.

Significant removal efficiencies were achieved: COD ($\eta > 80\%$), total N ($\eta > 70\%$) and total P ($\eta > 95\%$).

Better performances were displayed by the clayey soil. Plants irrigated with leachate, when compared to control units fed only with water and nutrient solution (Hoagland solution), developed a larger plant mass. Sunflower was the best performing species.

1. Introduction

Leachate treatment represents a massive cost in the management of solid waste. Due to the high concentration of contaminants, advanced technological treatments are required to reach the prescribed emission standards (Liu et al., 2015). A major concern is related to the qualitative changes which leachate undergoes over time during the landfill management phases (Kulikowska and Klimiuk, 2008; Lee et al., 2010). Young leachates with high BOD/COD ratio, high ammonium content and low pH can be successfully treated by means of biological treatment, while alternative treatments are used for the old leachates characterized by a significant fraction of recalcitrant compounds (humic acid, fulvic acid) and a high ionic strength (Stegmann and Ehrig, 1981; Cossu et al., 1992; Renou et al., 2008). In the majority of cases, leachate treatment is a combination of different processes, and both the production of secondary wastes (sludge, concentrate, brine) and the consumption of energy by each specific treatment step (Fane, 2007; Ehrig and Robinson, 2010) should be carefully considered at the time of selection of the most appropriate technologies.

Phytotreatment has been widely investigated and appears to be a valid alternative to energy-demanding processes (Jones et al., 2006). It is a sustainable process, featuring very low operational and maintenance costs, and is suited for use in treating weak leachates from old landfills, or for polishing leachates that have been pretreated by other biological processes (Ehrig and Robinson, 2010). Several plant species have been tested at lab and full scale by a series of authors and, in general, phytotreatment has displayed efficiency in the removal of recalcitrant contaminants, mainly due to soil and plant synergic effects (Fraser et al., 2004; Hasselgren, 1992; Akinbile et al., 2012). Plants treated with leachate grew better than those irrigated with water or did not differ significantly from plants treated with fertilizers (Cheng and Chu, 2011; Sang et al., 2010; Duggan, 2005; Jones et al., 2006; Marchiol et al., 2007; Tyrrel et al., 2001; Zalesny et al., 2007; Zupančič Justin et al., 2010). The use of plants for leachate treatment greatly increases evapo-transpiration compared to unvegetated sites, in which transpiration does not take place (Ettala, 1989). Increased evapo-transpiration is a desirable effect as it causes a reduction in the volume of leachate to be treated (Duggan, 2005; Ogata et al., 2015).

Phytoremediation of wastewater could be combined with the production of renewable energy, such as wood from short rotation coppice, bioethanol from lignocellulosic biomass or biodiesel from oleaginous crops (Pandey et al., 2016). The growth of energy crops, combined with wastewater treatment, increases the economic competitiveness of the system, reducing the costs associated with irrigation and fertilization (Duggan, 2005; Rockwood et al., 2004; Hasselgren, 1989). In recent years, the phytotreatment of leachate

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* Corresponding author.
E-mail address: mariacristina.lavagnolo@unipd.it (M.C. Lavagnolo).

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using plants for biomass and/or bioethanol production, has been partially explored by the scientific community, yielding interesting results on pollutant removal performances (Dimitriou and Aronsson, 2010; Duggan, 2005; Jones et al., 2006; Zalesny et al., 2007; Zupančič Justin and Zupančič, 2009).

This paper describes the results of an original research program in which three oleaginous plant species, *Helianthus annuus* (sunflower), *Glycine max* (soybean) and *Brassica napus* (rapeseed) were used to treat old landfill leachate. The three plant species have proved to be resistant to a series of organic and inorganic contaminants in different phytoremediation tests (Brunetti et al., 2011; January et al., 2008; Marchiol et al., 2007; Agostini et al., 2003; Schnoor et al., 1995). Moreover, oil for biodiesel production can be extracted from their seeds (Singh and Singh, 2010). Biodiesel yield and quality are influenced by oil composition; in particular the amount of Free Fatty Acids (FFA) should be <1% w/w. Feedstock with high FFA content decreases biodiesel yield and increases production costs. Different vegetable oils with varying fatty acid compositions can be used, although soybean, sunflower and rapeseed are the most widely employed. More than 95% of the world biodiesel is produced from edible oils such as rapeseed (84%), sunflower oil (13%), palm oil (1%), soybean oil and others (2%) (Atabani, 2012).

In this study, plants were grown both on sandy and clayey soil to test the effectiveness of leachate treatment in two different growing textures. The quality of the treated effluent depends on soil-water physical and chemical interaction, although leachate percolating through clayey soil should contain lower amounts of ammonia (Pivato and Raga, 2006) and COD than leachate percolating through sandy soil (Duggan, 2005).

The outcomes produced on plant growth and phytotreatment efficiencies have been discussed, together with the support of nitrogen and phosphorous mass balance, to better evaluate interactions between the different plants-soil-leachate components (Duggan, 2005).

2. Materials and methods

2.1. Equipment

A total of 24 pots (20 L volume each), 50 cm high, were equipped with a flexible tube at the bottom to control the water level inside the pot and drain off outflow.

10 cm of coarse gravels (8–16 mm in size) were arranged at the bottom as drainage layer. Twelve pots were filled with 30 cm of pure sand and twelve pots with 30 cm of clayey soil (Fig. 1).

Pots were placed inside a greenhouse, with controlled temperature (21–24 °C) and a 14-h photoperiod with 300 μmol m^{-2} s^{-1} light intensity.

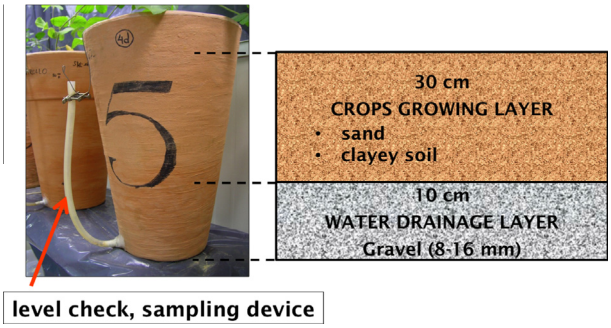

Fig. 1. Pots used during the experiment.

2.2. Landfill leachate

Leachate was collected from a confined capped landfill receiving unsorted municipal solid waste from 1987 to 1999, located in the North East of Italy.

This leachate can be classified as old landfill leachate (Table 1), as the pH value is high and BOD_5/COD below 0.1 (Kjeldsen et al., 2002; Andreottola and Cannas, 1992; Stegmann et al., 2005).

2.3. Chemical and physical properties of soils

Soil textures, determined using the Bouyoucos methods (Bouyoucos, 1962), are reported in Fig. 2. As expected, sandy soil belongs to the sand category, since pots were filled with pure sand.

The main characteristics of both clayey and sandy soils are reported in Table 2. As expected, the clayey soil featured a higher concentration of micro-nutrients (iron, copper, manganese) and macro-nutrients (nitrogen, phosphorous, potassium, calcium, magnesium, sulfur) than sandy soil.

2.4. Plants seeding and irrigation program

Seeds of the three plant species (sunflower, soybean and rapeseed) were germinated in peat soil; seedlings were irrigated with

Table 1
Characteristics of the leachate during the research period (mean values ± SD).

Parameter	Values	Parameter	Values
pH	8.02 ± 0.05	S^- (mg/L)	<4
TS (mg/L)	6315 ± 636	Cl^- (mg/L)	239 ± 12
VS (mg/L)	1548 ± 607	Ca (mg/L)	245 ± 13
COD (mg/L)	2255 ± 698	K (mg/L)	1075 ± 57
BOD_5 (mg/L)	75 ± 19	Mg (mg/L)	97.50 ± 5.20
TOC (mg/L)	1953 ± 259	Na (mg/L)	2705 ± 144
IC (mg/L)	140 ± 10	Cr (μg/L)	431 ± 23
TKN (mg/L)	1204 ± 30	Cu (μg/L)	54 ± 3
N-NH_4^+ (mg/L)	1117 ± 3	Fe (μg/L)	6690 ± 356
N-NO^{3-} (mg/L)	0.57 ± 0.13	Mn (μg/L)	171 ± 9
P (mg/L)	22 ± 3	Ni (μg/L)	144 ± 8
P-PO_4^{3-} (mg/L)	20 ± 1	Pb (μg/L)	49 ± 3
SO_4^{2-} (mg/L)	<10	Zn (μg/L)	171 ± 9

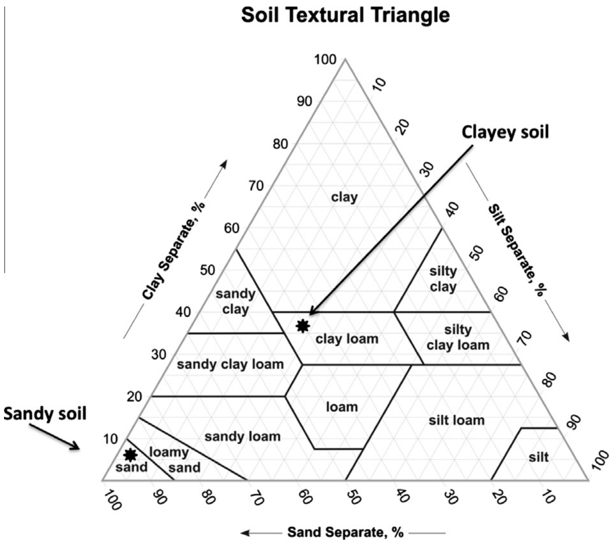

Fig. 2. Soils textures, classified according to USDA standards (USDA-NRCS, 1999).