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Different leachate phytotreatment systems using sunflowers

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ABSTRACT

The use of energy crops in the treatment of wastewaters is of increasing interest, particularly in view of the widespread scarcity of water in many countries and the possibility of obtaining renewable fuels of vegetable origin. The aim of this study was to evaluate the feasibility of landfill leachate phytotreatment using sunflowers, particularly as seeds from this crop are suitable for use in biodiesel production. Two different irrigation systems were tested: vertical flow and horizontal subsurface flow, with or without effluent recirculation. Plants were grown in 130 L rectangular tanks placed in a special climatic chamber. Leachate irrigated units were submitted to increasing nitrogen concentrations up to 372 mgN/L. Leachate was successfully tested as an alternative fertilizer for plants and was not found to inhibit biomass The experiment revealed good removal efficiencies for COD ($\eta > 50\%$) up until flowering, while phosphorous removal invariably exceeded 60%. Nitrogen removal rates decreased over time in all experimental units, particularly in vertical flow tanks. In general, horizontal flow units showed the best performances in terms of contaminant removal capacity; the effluent recirculation procedure did not improve performance. Significant evapo-transpiration was observed, particularly in vertical flow units, promoting removal of up to 80% of the inlet irrigation volume.

1. Introduction

The use of energy crops in the decontamination of wastewaters is of increasing interest, particularly in view of the widespread scarcity of water in many countries worldwide and of the possibility of obtaining renewable sources of energy (Tsoutsos et al., 2013; Zema et al., 2012).

Energy crops are defined as low-cost and fast-growing plants used to produce bioenergy and biofuels (such as bioethanol or biodiesel) or which can be burned to generate electricity or heat (Lal, 2008; Nges et al., 2012; Rowe et al., 2009).

Recent developments in the cultivation of energy crops have been driven by the need of advanced industrial societies to reduce both their dependence on fossil fuels as a source of energy, and the emission of greenhouse gases (Fernando et al., 2015; Lal, 2008).

The European Union strongly encourages and actively solicits the identification of means of improving the production of renewable energy (EC, 2009). Directive 2009/28/EC sets targets for each Member State, with the aim of reaching the 20-20-20 objective by 2020: reduction of 20% of greenhouse gas emissions compared to emissions in 1990; reduction of 20% of energy consumption due to the improvement of energy efficiency; 20% of energy consumption from renewable sources. The Directive, moreover, specifies a 10% mandatory target for biofuel utilization (Manãs et al., 2014; Spugnoli et al., 2012).

However, the specific cultivation of energy crops to fulfill the EU mandate may involve the use of high irrigation rates in order to produce relevant amounts of biomass. As a consequence, shortages in the supply of fresh water may ensue (Tsoutsos et al., 2013; Zema et al., 2012).

Nowadays, almost 70% of water consumption is linked to agricultural cultivations (FAO, 2015; United Nations, 2015), estimating an increase of 19% by 2050 (United Nations, 2015).

The use of unconventional water resources (raw or treated urban or industrial wastewater, landfill leachate) may represent an optimal compromise between the need to produce renewable energy and conservation of water supply (Zema et al., 2012).

Raw municipal wastewater has been tested on cultivations of *Typha latifolia*, *Arundo donax* and *Phragmites australis*, resulting in an up to 54% increase in average biomass yields compared to plants irrigated with conventional water (Zema et al., 2012).

Sewage sludge proved to be even more effective than commercial inorganic fertilizers in promoting biomass development of *Cynara cardunculus* L (Manãs et al., 2014).

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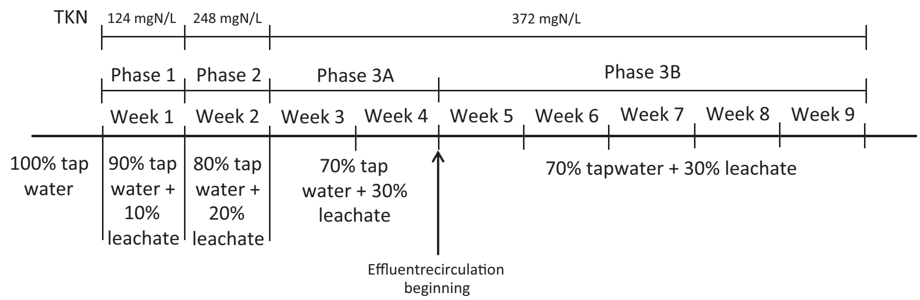

Fig. 1. Schematic research program of the entire experiment.

Helianthus annuus (sunflower) and *Ricinus communis* (castor) fed with the final effluent from a municipal wastewater treatment plant was characterized by a lower acidity value of extracted oil and a slightly lower viscosity compared to freshwater irrigated controls: wastewater irrigation seems to have a positive effect on biodiesel production as it simplifies the production process, as reported by Tsoutsos et al. (2013).

Poplar irrigated with diluted leachate had a greater height, diameter, and number of leaves, respectively, than control trees (Zalesny et al., 2009). In another study, diluted landfill leachate supplied to poplar and willow trees increased willow biomass production compared to corresponding controls, but not that of poplar (Dimitriou and Aronsson, 2010). In general, irrigation with wastewater or diluted landfill leachate is capable of effectively promoting the growth of energy plants, with plants then contributing to the removal of contaminants.

Helianthus annuus (sunflower), *Glycine max* (soybean) and *Brassica napus* (rapeseed) plants are considered optimal energy crops for use in Mediterranean and Continental areas. Lab-scale tests conducted using these three plant species irrigated with diluted landfill leachate and source separated sewage demonstrated how significant removal efficiencies can be achieved: COD ($\eta > 80\%$), total N ($\eta > 70\%$) and total P ($\eta > 95\%$) (Lavagnolo et al., 2016a, 2016b; 2011).

Sunflowers grow well in fertile and not-so-fertile areas, as well as in the presence of limited water availability (Skoulou et al., 2011). Sunflower plants grown in contaminated areas, or irrigated with landfill leachate or municipal/industrial wastewater, may represent a convenient option for use in producing alternative biofuel such as biodiesel.

The present study investigates the effects of diluted leachate irrigation on sunflower plants grown in tanks filled with soil under two different hydraulic regimes: vertical and horizontal subsuperficial flow. Nitrogen, phosphorous and organic (COD) contents were also monitored to control the ongoing process and to verify the efficiency of the treatment.

2. Materials and methods

2.1. Research program

The experiment was performed at the Laboratory of Environmental Engineering of the University of Padua (Italy).

Twelve 130 L polyethylene tanks were used: six set up as horizontal subsurface flow (HSSF) systems and six as vertical flow (VF) systems. Four HSSF tanks and four VF tanks were irrigated with diluted leachate; two HSSF and two VF were fed exclusively with tap water and used as controls ($HSSF_C$ and VF_C). All tanks were placed in a controlled climatic chamber. The experiment lasted 9 weeks and was divided into 4 phases, characterized by changes in the irrigation scheme (Fig. 1). The leachate dose was increased gradually to adapt the plants to the increasing concentration of contaminants and avoid a sudden failure caused by phytotoxicity phenomena (Cheng and Chu, 2011).

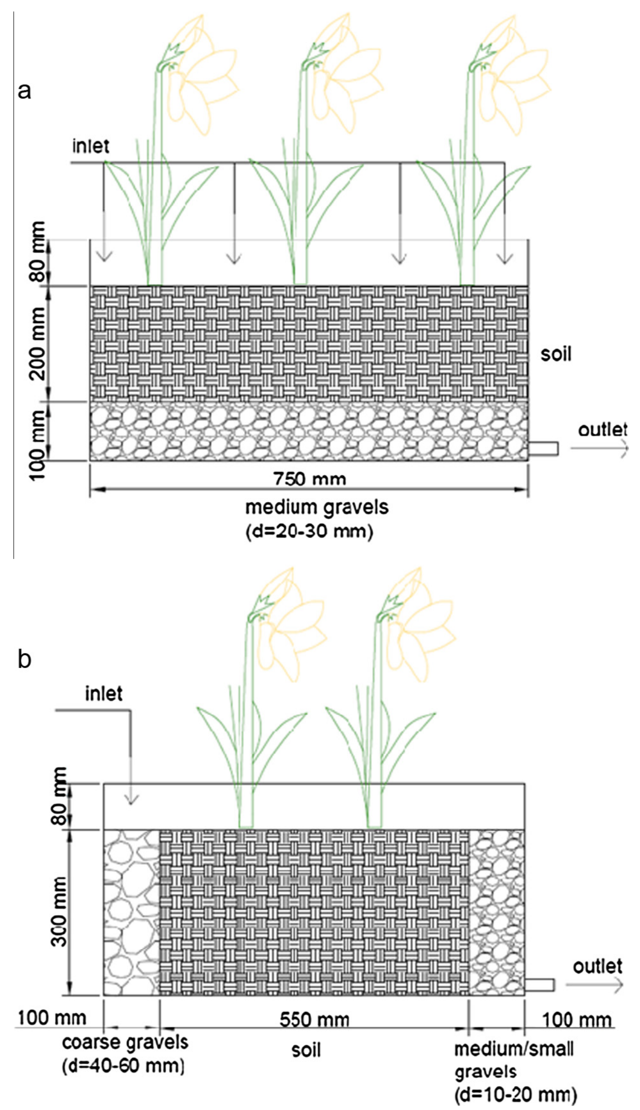

Fig. 2. Cross section of (a) vertical flow tank (VF, VF_R,VF_C) and (b) horizontal subsurface flow tank (HSSF, $HSSF_R$, $HSSF_C$).

Nitrogen concentration in the feed was used as a reference parameter in setting the irrigation timetable, as previous studies had revealed that nitrogen concentrations exceeding 400 mgN/L (Lavagnolo et al., 2016b; Leigue Fernández, 2014) may produce a negative effect on plants.