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Assessment of phytoremediation potential of native plants during the reclamation of an area affected by sewage sludge

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ABSTRACT

In this research paper the natural establishment of plants and their contribution to the reclamation of sewage sludge deposits through their uptake of nutrients and their bioconcentration factor (BCF) were investigated and assessed. The main research started in March 2012, and the plants growing naturally at the site under investigation during the first growing season (June 2012) were identified and recorded. On the basis of their occurrence and cover samples from ten species, namely *Amaranthus albus* L., *Amaranthus viridis* L., *Cardaria draba* (L.) Desv., *Chenopodium album* L., *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Lolium perenne* L., *Lycopersicon esculentum* Mill., *Malva parviflora* L., *Portulaca oleracea* L., were collected for chemical analyses. Macronutrients (Ca, Mg, K, P), trace elements (Mn, Cu, Zn, Fe, Cr, Ni, Pb) and Na were measured. The results showed that plants took up macronutrients at relatively high rates, in some cases reducing their excessive levels of concentration in the sludge by as much as 95%. Trace elements were removed at a lower rate compared to hyperaccumulators, this was possibly affected by their reduced bioavailability in the substrate, but the BCF, which was greater than one for most of the species and for most of the trace elements, indicated that the plants were capable of phytoextraction. It was concluded that selected native plants are not only tolerant to adverse environmental conditions, but also contribute by various processes to the reclamation of sites affected by sewage sludge.

1. Introduction

The disposal of residuals such as sewage sludge (biosolids) by applying them to agricultural land is widely practiced and presumed to be beneficial for plants' growth (Liphadzi and Kirkham, 2006). However, sewage sludge is often contaminated by heavy metals, organic pollutants, and pathogens. It is also characterised by a high water holding capacity and anaerobic conditions, and malodours associated with the presence of some volatile organic compounds (VOCs), even after digestion and alkaline stabilisation (Laor et al., 2010). These aspects present the main obstacles to applying sewage sludge to the land and explain why treated sewage sludge, if not landfilled or incinerated, often remains within the territory of Wastewater Treatment Plants (WWTPs) without further utilisation. Economic considerations and traditions may also be of relevance. In Greece, for example, owing to a lack of acceptance by farmers, most sludge is landfilled. According to Matthews (1999) and IEEP (2009) the country uses very small quantities of sludge in agriculture (~10%), and these mostly in the frame of research projects and pilot studies. However, in the last few years interest in using sludge in this sector has increased. According to the data of the Thessaloniki Water Supply and Sewerage Co, SA (EYATH) approximately 1000 ton of sewage sludge were used by the agricultural sector in Thessaloniki in 2010/2011 and more than 7000 ton in 2012, and the trends are growing for 2013 (Zambetoglou, K., personal communication). Besides the agricultural sector, sewage sludge can also be used as an amendment for mine spoils

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reclamation (Brofas et al., 2000) and in the cement industry (Christoulas et al., 2000). However, this is still very much at the experimental stage in Greece. Meanwhile, heaps of sewage sludge accumulated within the territory of Greek WWTPs may have an adverse effect on the environment and human health. In order to protect the environment and to enhance residual utilisation sewage sludge should be reclamated. In the case of sewage sludge, when vast areas of land are affected, phytoremediation may be a more economical and effective remediation strategy than conventional treatments (Tappero et al., 2007).

A key factor in phytoremediation technology is the selection of plant species, as the plants should have the appropriate characteristics to allow them to grow in site-specific conditions (i.e. waste characteristics, climate, etc.), and to meet the objectives of phytoremediation. The consideration of the use of native plants which already grow at a site is one of the starting points for the selection process (US EPA/600/R-99/107, 2000). That is why in recent years many research projects have focused on investigating plants which have established themselves naturally at contaminated sites and on determining their contribution to the degradation of contaminants. Thus, Alifragkis et al. (2013) investigated the establishment of plants that grow naturally in mining areas after chemical stabilisation and phytoremediation. The authors evaluated the phytoremediation potential of thirty-three different plant species and concluded that some, for example *Verbascum undulatum* Lam., could be classified as heavy metals hyperaccumulator. Studies of native plants in mining areas were also conducted by Murciego et al. (2007) and Salas-Luévano et al. (2009). The former authors found that *Cytisus striatus* (Hill) Rothm. could act as an excluder, while *Cistus ladanifer* L. and *Dittrichia viscosa* (L.) Greuter – as accumulators during the phytoremediation of soils polluted with Sb. The latter authors concluded that only *Buddleja scordioides* Kunth was a good possible choice for Pb phytoextraction, while *Acacia schaffneri* (S. Watson) F.J. Herm., *Lupinus campestris* Schltdl. & Cham., and *Amaranthus hybridus* L. adapt well to adverse environmental conditions, especially to the presence of Pb. Two native plant species, *Globularia alypum* L. and *Rosmarinus officinalis* L., grown on a former industrial site, were classified by Testiati et al. (2013) as excluders and proposed for the phytostabilisation of metals. Tiwari et al. (2008) recorded the high metal accumulation potential of *Portulaca tuberosa* Roxb. and *Portulaca oleracea* L. growing at an area irrigated by industrial effluent. Having examined forty-three different plant species, Porębska and Ostrowska (1999) proposed the use of *Lactuca serriola* L., *Artemisia vulgaris* L., *Chenopodium album* L. and *Atriplex sagittata* Borkh. for the phytoremediation of sludge and other waste substrates (municipal landfill, smelter protection zone and others).

In the area of the Thessaloniki WWTP (ThWWTP) and for the express purpose of phytoreclamation of sludge, experimental trials using four species, namely *Populus alba* L., *Robinia pseudoacacia* L., *Quercus pubescens* Willd. subsp. pubescens, *Pinus pinea* L., were performed in the spring of 2012. Whilst preparing this experiment, it was noticed that many herbaceous species were already naturally established in the experimental units. Furthermore, a strong differentiation of species composition and cover was recorded between the experimental units. On the basis of the above-mentioned observations, additional research aims were formulated in order to investigate which species naturally establish themselves and grow on sludge. More specifically, the present paper aims at (i) the recording of the naturally established flora on the sludge treatments, (ii) the investigation of species composition and diversity differentiation between the different treatments and (iii) the assessment of accumulation of nutrients and heavy metals in these plants in the context of their usefulness for sludge reclamation.

2. Materials and methods

2.1. Site description

The experimental site was set up at the ThWWTP in Sindos, which is the biggest municipal WWTP in Thessaloniki, Greece (coordinates 40°39′47.14″ N, 22°50′01.32″ E). It receives around 180,000 m^3 of domestic wastewater daily from Thessaloniki's urban area via the central sewage system, as well as approximately 1500 $m^3\ day^{-1}$ of wastewater from areas with hauled waste (Suchkova et al., 2010). The plant also receives some amount of local urban runoff, mainly composed of atmospheric deposition and traffic-related emissions deposited on the road surface, and also runoff from industrial and harbour areas. The treated wastewater is discharged into the Thermaikos Gulf via a submarine outfall. Sewage sludge is anaerobically digested, thickened, and dewatered with a polyelectrolyte addition in belt filter presses, giving a product of about 23% in solids. Up to 2012 dewatered sludge was treated with alkaline material for chemical stabilisation and pathogen reduction. Since 2012 it has been directed to the drying unit, giving a final product of about 95% in solids, some of which is stored at the plant, and some of which is removed out (Kotoulas, K., personal communication).

The area of the ThWWTP belongs to the Northern Continental – Mediterranean climatic zone of Greece (Kotini-Zambaka, 1983) with average minimum and maximum monthly temperatures of +4.7 °C (January) and +26.5 °C (July), respectively. The winters are sometimes cold and there is often frost (−1.5 °C). The mean annual precipitation is 453 mm. In geological terms the area of Sindos village belongs to the metamorphic alpine formations of the Thessaloniki-Giannitsa tectonic depression which consists of Tertiary (thickness of more than 3000 m) and Quaternary deposits (thickness of more than 750 m) (Mercier, 1966). Specifically the area is located on deposits such as sandy silts, sandy clays with peat, sands, clays, sandy gravels with pebbles, conglomerates, and covered with several metres of alluvial soils. Currently in some places topsoil is covered with older sludge heaps. There are three aquifers in the area: in the lacustrine–marine sediments, with poor water quality down to a depth of about 90 m; in the Quaternary deposits (gravel, pebbles), with water suitable for municipal supply; and in the sandstone–marl series, with poor water quality.

2.2. Experimental approach

The establishment of the experimental site initiated in early January 2012. Seven ditches were dug using a tractor. Each ditch was filled with a mixture prepared as shown in Table 1. In early March 2012 the treatments T1–T3 were planted with *Populus alba* (2 years old), *Robinia pseudoacacia* (1 year old), *Quercus pubescens* (less than 1 year old) and *Pinus pinea* (less than 1 year old). The control units C1–C4 were not planted. An automatic dripping irrigation system was installed in all experimental units and used for 3 h early in the morning three times per week during the dry season. In early April 2012 a natural revegetation process was observed in all the experimental units (T1–T3, C1–C3). The present paper is exclusively concerned with the study of the native plants, while tree species are not discussed. Since the tree species only had a small crown and root system at the time of studying the native plants, their effect on the natural colonisation process is considered as not important.

2.3. Data collection

2.3.1. Sewage sludge

In early January 2012 and before the experiment began, sewage sludge, that had been dewatered on filter presses, and that was