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Sewage sludge, compost and other representative organic wastes as agricultural soil amendments: Benefits *versus* limiting factors

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A B S T R A C T

Nine different samples of sewage sludges, composts and other representative organic wastes, with potential interest to be used as agricultural soil amendments, were characterized: municipal sewage sludge (SS1 and SS2), agro industrial sludge (AIS), municipal slaughterhouse sludge (MSS), mixed municipal solid waste compost (MMSWC), agricultural wastes compost (AWC), compost produced from agricultural wastes and sewage sludge (AWSSC), pig slurry digestate (PSD) and paper mill wastes (PMW). The characterization was made considering their: (i) physicochemical parameters, (ii) total and bioavailable heavy metals (Cd, Cr, Cu, Ni, Pb, Zn and Hg), (iii) organic contaminants, (iv) pathogenic microorganisms and (v) stability and phytotoxicity indicators. All the sludges, municipal or other, comply with the requirements of the legislation regarding the possibility of their application to agricultural soil (with the exception of SS2, due to its pathogenic microorganisms content), with a content of organic matter and nutrients that make them interesting to be applied to soil. The composts presented, in general, some constraints regarding their application to soil, and their impairment was due to the existence of heavy metal concentrations exceeding the proposed limit of the draft European legislation. As a consequence, with the exception of AWSSC, most compost samples were not able to meet these quality criteria, which are more conservative for compost than for sewage sludge. From the results, the composting of sewage sludge is recommended as a way to turn a less stabilized waste into a material that is no longer classified as a waste and, judging by the results of this work, with lower heavy metal content than the other composted materials, and without sanitation problems.

1. Introduction

The Landfill Directive (Council Directive 1999/31/EC) required a diversion of organic wastes sent to landfills in order to reduce the emission of greenhouse gases. An alternative could be their beneficial application in agricultural soils, which allows maintaining or restoring the quality of soils, reducing the need for inorganic fertilisers, with a net contribution to the end-of-waste policy in Europe (Mantovi et al., 2005; Council Directive 2008/98/EC; Fytili and Zabaniotou, 2008; Goss et al., 2013; Saveyn and Eder, 2014). However, a wide variety of undesired traits can have adverse effects on the environment as a consequence of this practice (Aparicio et al., 2009; Smith, 2009a, 2009b; Clarke and Smith, 2011; Kupper et al., 2014). That is why it is very important to gather knowledge on the risk of the use of sewage sludge, compost and other representative organic wastes as agricultural soil amendments.

Sludge reuse in agriculture was first regulated in the European Union (EU) by the Council Directive 86/278/EEC, which primary aim was the environment, especially the soil, and the human health protection against the sludge born metals. While this Directive is currently under revision (Fytili and Zabaniotou, 2008), some member states, like Portugal, have evolved to more updated legislation, introducing criteria for organic contaminants and pathogenic indicator microorganisms (Decree-Law No. 276/2009). The use of indicator microorganisms (bacteria and viruses) to estimate the sanitary risk related to sludge application to soil is very impor-

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tant, since some researchers have alerted to the potential risk of contamination of soil and water by pathogens present in sludge (Sidhu and Toze, 2009), especially sludge produced in rural wastewater treatment plants, which are generally spread on fields without any sanitation procedure (Pourcher et al., 2007).

As for the organic contaminants, the 3rd draft of the "Working document on sludge" (European Commission, 2000) proposed limit values for the so-called sum of halogenated organic compounds (AOX), linear alkylbenzene sulphonates (LAS), di(2-ethylhexyl)phthalate (DEHP), nonylphenole and nonylphenole ethoxylates (NP/NPE), polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and polychlorinated dibenzo-p-dioxins and -furans (PCDD/F) (Langenkamp and Part, 2001). Several authors (Smith, 2009b; Clarke and Smith, 2011) have reviewed the research made on organic contaminants concentrations in treated sewage sludge, and they have concluded that there is a growing body of evidence demonstrating that the majority of the studied compounds do not endanger human health when they are recycled to farmland.

Not only sewage sludges have potential interest to be land applied (Goss et al., 2013). Also agro-industrial sludges, for instance from the sugar production (Alvarenga et al., 2008), pulp and paper mill sludges (Phillips et al., 1997; Rato Nunes et al., 2008), and slaughterhouse sludges, have a chemical composition that makes them potential candidates to be land applied.

The reuse of sewage sludge for agricultural purposes faces technical problems, not only because of its pollutant load, but also due to the fact that sludge is being produced all year round, whereas its application on land takes place once or twice a year (Fytili and Zabaniotou, 2008). One solution is the construction of facilities where the sludge can be stored for some time and, ideally, composted with other organic wastes, namely agricultural wastes. The co-composting of sludge would improve its quality, overcoming some of its problems, namely its high water content, contamination with pathogenic microorganisms, lack of stability, and even, in some cases, contributing to a lowering of the availability of metals in amended soils (Smith, 2009a).

In fact, composting and anaerobic digestion represent well established processes for waste management in Europe, but the Member States follow different approaches when determining the status of compost, i.e., whether it is considered a waste or not (Smith, 2009a; Kupper et al., 2014; Saveyn and Eder, 2014). As for the EU, a long time effort has been made to create regulation concerning compost quality; for some time the 2nd Draft (DG Env.A.2., 2001) has been used as a guide document, although it has never had a final version, and, today, we have a Report on End-of-waste criteria (Saveyn and Eder, 2014), which can be used to overlap the absence of regulations in Portugal.

In this context, the aims of this study were: (i) to characterize a battery of sewage sludges, organic wastes, and composts made from sewage sludges or organic wastes, in order to assess their potential beneficial effects against detrimental impacts of their application to soil; (ii) to compare the measured data to literature and legislative values; and (iii) to highlight the need to create national and EU regulations concerning organic wastes and compost quality criteria to be used on agricultural land.

This paper presents the results on the organic materials': (i) physicochemical characteristics, (ii) total and bioavailable heavy metal concentration (Cd, Cr, Cu, Ni, Pb, Zn and Hg), (iii) organic contaminants, (iv) pathogenic microorganisms (*Escherichia coli* and *Salmonella* spp), and (v) stability and phytotoxicity indicators, and represents a first approach to the risk evaluation of their application to soil in an ongoing project entitled: "ResOrgRisk – Environmental risk assessment of the use of organic residues as soil amendments" PTDC/AAC-AMB/119273/2010, from "Fundação para a Ciência e Tecnologia" (FCT).

2. Materials and methods

2.1. Samples

Nine different samples of sewage sludges, composts and other representative organic wastes, hereafter referred as organic materials, were collected at different locations in Portugal.

Two samples of untreated dewatered municipal sewage sludges (SS1 and SS2) were collected from different municipal wastewater treatment plants (WWTP): the first, SS1, from WWTP1, which serves a big city of 134000 inhabitants in the Algarve region, and a second one, SS2, from WWTP2, which serves a small village of 6000 inhabitants in Alentejo region, with rural characteristics. Both WWTP have activated-sludge treatment processes, with high aeration rate, followed by nitrification-denitrification, and by chemical phosphorous removal at WWTP1. The sludges are mechanically dewatered by centrifugation, allowing about 15% dry matter content, and were, at the time, sent to landfill.

An agro industrial sludge (AIS), was collected in a WWTP from a large winery in Alentejo region (South of Portugal) (9000 m^3 average annual production). The wastewater is subjected to biological treatment in a reactor, with O_2 injection, and the sludge is subjected to gravity separation, after conditioning with an electrolyte, chemically stabilized by the addition of lime, and squeezed mechanically. The sludge is usually sent to landfill.

A municipal slaughterhouse sludge (MSS) was also collected, which is generated in the pre-treatment of the wastewater produced in the animal slaughtering (pigs, cattle, sheep and goats), and in the meat and sub-products processing, subsequently sent to the municipal WWTP (Alentejo region). The sludge is mechanically dewatered and chemically stabilized by the addition of lime. This sludge is also usually sent to landfill.

Mixed municipal solid waste compost (MMSWC), was obtained in a composting plant near Setúbal, which serves about 113,000 inhabitants. The composting plant receives unsorted municipal solid waste, which is mechanically segregated and biologically treated. The compost produced is commercialized in bulk, mainly to be land applied in vineyards in Alentejo region (Portugal).

The agricultural wastes compost (AWC), was produced in a farm located southeast from the town of Serpa (Alentejo), dedicated to the cultivation of olive trees in accordance with the rules of organic farming. The compost was produced from the wastes of the cleaning of olive groves, and of the harvesting and processing of the olives, to produce olive oil, and from manure generated in the farm. The following proportions of materials were used: 21% of olive mill waste, 61% of sheep manure, 10% of olive leaves, and 8% of meat flour (added to achieve a proper C/N ratio). All the compost produced is usually used in the organic amendment of the soils of the farm.

A compost produced from agricultural wastes and sewage sludges (AWSSC), was obtained from a composting plant located in the centre of Portugal, which is licensed to collect and temporarily storage sewage sludges and other different organic wastes, mainly agricultural wastes from the local producers. These wastes are mixed together, usually 30% sewage sludge, 25% agricultural wastes, and 45% woody materials, and let to stabilize by composting. This composting plant provides a sustainable solution for sewage sludge and other different organic wastes, assuring the flow of sewage sludge in the period from November to January, when the application of sewage sludge in agricultural soils is prohibited. The compost produced is commercialized with a commercial brand.

A pig slurry digestate (PSD) was obtained from a collective treatment plant which receives the effluents produced by several pig farms, of small and medium size, scattered in a Natural Park area in the centre of Portugal (*Serra de Aire e Candeeiros*). The effluent