Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Recycling organic wastes to agricultural land as a way to improve its quality: A field study to evaluate benefits and risks

P. Alvarenga [a,b,*], P. Palma [a,c], C. Mourinha [a], M. Farto [a], J. Dôres [a], M. Patanita [a,d], C. Cunha-Queda [b], T. Natal-da-Luz [e], M. Renaud [e], J.P. Sousa [e]

[a] Department of Applied Sciences and Technologies, Polytechnic Institute of Beja, Beja, Portugal
[b] LEAF – Linking Landscape, Environment, Agriculture and Food, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal
[c] CIMA – Centro de Investigação Marinha e Ambiental, FCT, Universidade do Algarve, Faro, Portugal
[d] GeoBioTec, FCT, Universidade NOVA de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal
[e] CFE – Centre for Functional Ecology, Department of Life Sciences, University of Coimbra, Coimbra, Portugal

ARTICLE INFO

Article history:
Received 25 August 2016
Revised 31 December 2016
Accepted 2 January 2017
Available online xxxx

Keywords:
Sewage sludge
Compost
Soil organic amendment
Recycling
Trace elements
Field experiment

ABSTRACT

A field study was established to assess the effects of a sewage sludge (SS), a mixed municipal solid waste compost (MMSWC) and a compost produced from agricultural wastes (AWC), in a Vertisol, using *Lolium multiflorum* L. The amendments were applied for two consecutive years: 6, 12 and 24 t dry matter ha^{-1} for SS, and the amendment doses for MMSWC and AWC were calculated to deliver the same amount of organic matter (OM) per unit area. The amendments had significant beneficial effects on some soil properties (*e.g.* soil OM, $N_{Kjeldahl}$, extractable P and K), and on plant productivity parameters (*e.g.* biomass yield, chlorophyll, foliar area). For instance, soil OM increased from 0.78% to 1.71, 2.48 and 2.51%, after two consecutive years of application of 24 t dry matter ha^{-1} of SS, MMSWC and AWC, respectively, while the plant biomass obtained increased from 7.75 t ha^{-1} to 152.41, 78.14 and 29.26 t ha^{-1}, for the same amendments. On the plant, effects were more pronounced for SS than for both compost applications, a consequence of its higher capacity to provide N to the plant in a readily available form. However, after two years of application, the effects on soil properties were more noticeable for both composts, as their OM is more resistant to mineralization, which endures their beneficial effects on soil. Cadmium, Cr, Ni and Pb pseudo-total concentrations, were not affected significantly by the application of the organic wastes to soil, in all tested doses, neither their extractability by 0.01 M $CaCl_2$. On the contrary, Cu and Zn pseudo-total concentrations increased significantly in the second year of the experiment, following the application of the higher rate of MMSWC and AWC, although their extractability remained very low (<0.5% of their pseudo-total fraction). Trace elements concentrations in the aboveground plant material were lower than their maximum tolerable levels for cattle, used as an indicator of risk of their entry into the human food chain. Despite these results, it is interesting to note that the SS promoted a significant increase in the foliar concentrations of Cu, Ni and Zn that did not happen in composts application, which can be explained by the reduction of the soil pH, as a consequence of SS degradation in soil. Concluding, if this type of organic wastes were to be used in a single application, the rate could be as high as 12 or even 24 t ha^{-1}, however, if they are to be applied in an annual basis, the application rates should be lowered to assure their safe application (*e.g.* to 6 t ha^{-1}). Moreover, it is advisable to use more stable and mature organic wastes, which have longer lasting positive effects on soil characteristics.

1. Introduction

The European Waste Framework Directive (Council Directive 2008/98/EC) has introduced a paradigmatic shift in waste management: the possibility of continuing the life cycle of materials should be considered, in the perspective of a circular economy. In this context, it is very important to consider the agricultural beneficial use of organic rich wastes, alternative to their landfilling or incineration, which will allow the organic matter and nutrient recycling, contributing to the "End-of-Waste" policy in Europe (Mantovi et al., 2005; Council Directive 2008/98/EC; Fytili and Zabaniotou, 2008; Fernández et al., 2009; Saveyn and Eder, 2014).

* Corresponding author at: Department of Applied Sciences and Technologies, Polytechnic Institute of Beja, Beja, Portugal.
E-mail address: paula.alvarenga@ipbeja.pt (P. Alvarenga).

http://dx.doi.org/10.1016/j.wasman.2017.01.004
0956-053X/

This is a potentially important strategy, since in Portugal, as in other Mediterranean countries, cropland soils have usually very low topsoil organic matter content and are very prone to erosion (Sánchez-Monedero et al., 2004; Antolín et al., 2005; Fernández et al., 2009). To overcome this problem, the use of organic wastes as soil improvers is attractive, because they: (i) enhance soil organic C storage, (ii) enable valuable components to be recycled (*e.g.* N, P and K), (iii) promote the formation of stable aggregates; (iv) improve water holding capacity, soil aeration and cation exchange capacity (Antolín et al., 2005; Larchevêque et al., 2006; Fernández et al., 2009; Diacono and Montemuro, 2010; Mattana et al., 2014). In fact, in adequately sludge-amended soils, crop yield can be higher than in well-fertilized soils (Singh and Agrawal, 2008), and the long-term advantages on soil properties are very important, as Mantovi et al. (2005) have found in a twelve-year field experiment with liquid, dewatered and composted sewage sludge (5 and 10 t DM ha^{-1} yr^{-1}): OM, total N and available P have increased, while alkalinity has decreased.

However, the use of sludges and composts produced from organic wastes as fertilizers represents a potential risk to the environment, because of the high contaminants content often found in the organic wastes (*e.g.* metals, organic contaminants, and pathogenic microorganisms). This risk may be aggravated if those contaminants are mobilized in the soil, which turns them available for plant uptake and/or to be transported in drainage waters (Aparicio et al., 2009; Smith, 2009a, 2009b; Clarke and Smith, 2011; Kupper et al., 2014). In fact, bioavailability of metals may increase for many years in soils amended with excessive rates of sludge (Singh and Agrawal, 2008). Mantovi et al. (2005), with the results from twelve years of continuous biosolid land spreading, elected some risks to soil: a small build-up of heavy metals, especially Cu and Zn, increased availability of P, that can be hazardous for water eutrophication, and the higher Zn content of amended soil, that, in conjunction with pH reduction, could affect soil ecology due to Zn accumulation.

In fact, if a sludge is intended to be used as fertilizer in growing crops for human consumption and feed production, a strong emphasis should be given to the biological and chemical safety of the material (Roig et al., 2012; Cieslik et al., 2015). The Sludge Directive (Council Directive 86/278/EEC) is currently under revision (Fytili and Zabaniotou, 2008; European Commission, 2014), to reduce the standard limit values for metals, and set limits for emerging organic pollutants and hygienic indicator parameters (Mininni et al., 2015). Moreover, the application of fresh organic wastes, like raw sewage sludges, can also be problematic and affect negatively soil properties and plant growth, even for sludges with low contaminants load (Fernández et al., 2009). An option to cope with some of the risks from the organic wastes application to soil is their composting (Roca-Pérez et al., 2009). This biological treatment arises as an important option for the organic waste management, with environmental and economic benefits, as allows for the biooxidation of organic matter into a more stable and less degradable material, free of phytotoxic compounds, pathogens, parasites and weed seeds, and partially humified (Bernal et al., 1998; Cunha-Queda et al., 2002; Bernal et al., 2009; Fernández et al., 2009; Raj and Antil, 2011). That is why, in the assessment of compost quality for soil application, it is important to consider not only their contaminants content but also their maturity and stability (Wu et al., 2000; Ko et al., 2008; Alvarenga et al., 2016a). However, Cesaro et al. (2015) reviewed the European regulations and guidelines used to evaluate compost quality and alerted for their lack of uniformity. In Portugal, the recently published legislation for fertilizing materials, Decree-Law No. 103/2015, allowed the fulfilment of a gap on the safe application of composted materials to soil legislation, but will create, at the same time, some problems to the compost producers, due to the stringency of the limit values for some of the contaminants, especially trace elements.

Considering the above, it is obvious the importance of evaluating the benefits and potential risks of the application of sludges and composted organic wastes to agricultural soils. Only by increasing knowledge in this area, it will be possible to progressively contest the opposition of the local stakeholders to the use of sludge and organic wastes' compost as fertilizers. To make that possible, it is important to work with the municipal wastewater treatment plant (WWTP) operators whom will need to invest in stabilization processes, and update some treatment infrastructure (Mininni et al., 2015). Another important step is the awareness effort for the separation at the source of wastes intended to be composted, which would reduce the contaminant content of the compost produced (Cesaro et al., 2015).

In previous studies, Alvarenga et al. (2015, 2016a, 2016b) carried out a full characterization of nine organic wastes, potentially interesting to be used as organic soil improvers, already available to the end-users. It was possible to verify that, for certain sewage sludges, the major limitation to their application is related to the pathogenic microorganisms' concentrations, a consequence of the lack of a final stabilization step in their production. However, regarding their content of heavy metals and organic contaminants, they comply with the Portuguese legislation (Decree-Law No. 276/2009) and Council Directive 86/278/EEC. In the case of composts produced from organic wastes, the Portuguese legislation is recent (Decree-Law No. 103/2015) and shows a more protectionist tendency for soils than the legislation on sludge. It is for that reason that some important composts available locally presented problems concerning their total metals content (Alvarenga et al., 2015). Therefore, even though the use of these sewage sludges and composts is prohibited in soils intended for some specific agronomic practices, they can be used for other activities, such as silviculture, green spaces and land reclamation (Sánchez-Monedero et al., 2004). Consequently, there is a basic need to know the benefits and risks of their land application, especially to better understand the behaviour of metals in soil, conveyed by materials with distinct degree of stabilization, which can affect their availability and the potential risks of their entry into the human food chain.

Taking this in account, a field experiment was established with the application of three of the organic materials selected from the previous study: a sewage sludge (SS), a mixed municipal solid waste compost (MMSWC), and a compost produced from agricultural wastes (AWC) in different doses, in plots sown with *Lolium multiflorum* L., in order to assess the effects of the amendments: (i) on the soil properties (a Vertisol); (ii) on the plant nutritional status and productivity; and (iii) on the behaviour of metals in the soil/plant system. The experiment was repeated in two successive seasons, to evaluate the potential cumulative effects of metals in soils and the mid-term effects on the soil fertility parameters that could arise from the application of organic materials with different degrees of stability and maturity. With these results, maybe it will be possible to recommend application doses, or limitations to those doses.

2. Materials and methods

2.1. Organic wastes characteristics

Dewatered municipal SS was obtained from a municipal wastewater treatment plant (WWTP), located in a small village of 6.000 inhabitants in Alentejo (Portugal), with rural characteristics. The WWTP has activated-sludge treatment, with high aeration rate, followed by nitrification-denitrification. The sludge is

Please cite this article in press as: Alvarenga, P., et al. Recycling organic wastes to agricultural land as a way to improve its quality: A field study to evaluate benefits and risks. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.01.004