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Changes in the functional properties of a sandy loam soil amended with biosolids at different application rates

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ABSTRACT

The goal of this research was to study the impact of the application rate of biosolids from municipal sewage sludge on soil functionality. The biosolids originated from the composting of aerobic or anaerobic municipal sewage sludge with rice husk in the ratio 1/1 v/v. The products were applied at increasing doses, 50 (1×), 150 (3×), and 300 (6×) mg N $kg^{-1}{}_{ds}$, on a sandy loam soil. In order to highlight their impact on soil properties and evaluate their possible deleterious effects, soil functional parameters (soil microbial biomass, soil enzyme activities, and soil bacterial population) were used. Outcomes showed that the increase of the application rate had significant impact on microbial biomass carbon, which increased by 5%, 9% and 21% in 1×, 3× and 6× with respect to the untreated soil. Biosolid application rate influenced soil enzyme activities, such as β-glucosidase, dehydrogenase, protease and alkaline phosphomonoesterase which sharply increased at 3× and 6×, especially in the soils amended with the aerobic biosolid. Soil total bacterial population proved to be stable and not affected, at any dose, by biosolid addition.

Concerning total trace metals, no dose effect was registered, as their concentrations were the same for each dose and treatment; on the contrary, available copper diminished with application rate. On the whole, soil functionality was not negatively affected by biosolid application.

1. Introduction

The use of organic amendments, such as municipal solid waste (MSW) and sewage sludge (SS), is a common practice to improve physical, chemical and biological properties of depleted soils by supplying organic matter (Carbonell et al., 2011). In particular, sandy soils, that are poor in clay minerals and organic colloids, are affected by low fertility caused by low water holding capacity and shortage of nutrients. Good agricultural practices involve frequent applications of organic fertilizers, both conventional, such as manure or plant residues, as well as non-conventional, such as peat, brown coal and SS. Their addition not only improves soil properties but also helps to solve serious environmental problems concerning disposal of large quantities of different wastes (Weber et al., 2007). Depending on the nature and treatment, organic amendments may affect size and activity of soil microflora; indeed soil microorganisms are essential to agricultural systems, playing an important role in cycling carbon and nutrients and therefore affecting soil fertility (Nannipieri et al., 2002).

On the other hand, current guidelines and regulations require MSW and SS to be properly treated before land application to reduce pathogens, minimize environmental risks and enhance agronomic performances (CEC, 1986; Franco-Otero et al., 2012; US EPA, 1993; US EPA, 1994). Composting represents an established treatment option, by which MSW and SS are subjected to controlled aerobic conditions designed to promote biological degradation and transformations of organic matter into a humus-like product (Epstein, 1996). Moreover, community legislation in the European Union (EU) considers that biosolids, MSW and SS composts may substantially benefit the climate change given their action on carbon sequestration (European Community, 2001).

However, according to several works, the main sources of metal input in agricultural soils include the use of SS compost (Carbonell et al., 2009) and MSW compost (Smith, 2009), which are of particular concern because of their potential risk for the environment (Carbonell et al., 2011). Thus, the beneficial aspect of compost amendment should be assessed together with the potentially detrimental ones (Weber et al., 2007).

MSW and SS composts in recent decades have received great attention (Senesi et al., 2007) and the literature on the effects of organic amendments on soil microbial biomass activity is extensive. Most studies have consistently shown enhancement of soil microbial biomass carbon, basal respiration and enzyme activities, with variations in soil microbial community structure (Bastida et al., 2008; Garcia-Gil et al., 2004, 2000), but, in some cases, also an increase of heavy metal concentration has been found (Baldantoni et al., 2010; Garcia-Gil et al., 2000).

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In the latest years Fernandez et al. (2007) focussed their attention on the comparison of thermally dried and composted SS in a short-term lab-scale experiment and in a mid-term field study (Fernandez et al., 2009). Recently Franco-Otero et al. (2012) investigated the short-term effect of such amendments on microbial biomass, activity and soil chemical properties.

In a previous work (Sciubba et al., 2013) we evaluated the effects on soil fertility of biosolids obtained by composting urban SS and rice husk, which had, at the employed compost dose (50 mg N $kg^{-1}{}_{ds}$ corresponding to 8 Mg $ha^{-1}{}_{dm}$ approximately), a weak effect on enzyme activities and heavy metal concentration.

Brown and Cotton (2011) carried out a field survey in California to quantify the benefits of applying compost to agricultural soils, in farm sites, at different application rates. Their results showed an improvement in some soil quality indicators (soil organic carbon, bulk density, nutrients availability, and soil respiration) as a result of compost application and underlined that the largest response to compost amendment was found in the sites that received the highest cumulative loading rates. Moreover, in this study the effects of compost application rates were less clear, despite the trends towards more pronounced differences in soil properties with higher application rates, as other factors such as soil texture influenced the measured variables (Brady and Weil, 2002). It is likely that a higher control of other factors including soil type would lead to a more linear response to increased compost application rates (Brown and Cotton, 2011) and this could be achieved in a lab-scale experiment.

The effects of biosolids on soil quality can be expressed through the use of indicators such as microbial biomass content, metabolic quotient, microbial C-to-organic C ratio, soil enzymatic activities (Anderson and Domsch, 1990; Baath, 1989; Brookes, 1995; Dick, 1994; Giller et al., 1998; Pavan Fernandes et al., 2005; Wardle and Ghani, 1995) and studying the biodiversity of the soil indigenous microbial community (Sampedro et al., 2009), as the application of biosolids can stimulate soil microbial activity, due to an increase in available carbon and nutrients, or inhibit activity, due to the presence of heavy metals and other pollutants (Pavan Fernandes et al., 2005).

Particularly, microbial activity and soil fertility are closely related because it is through the biomass that mineralization of important organic elements (C, N, P, and S) occurs (Frankenberger and Dick, 1983; Garcia-Gil et al., 2000). Studies on microbial biomass carbon and enzyme activities provide information on the biochemical processes occurring in soil and there is evidence that soil biological parameters are early and sensitive indicators of soil ecological stress and restoration (Dick and Tabatabai, 1992), especially in soil treated with organic amendments.

Moreover, fingerprinting DNA-targeted molecular analyses are employed to get more insights into the structure and dynamics of microbial based processes and ecosystems, where just 1% of the total biomass is cultivable (Amann et al., 1995). In particular, PCR–DGGE (Denaturing Gradient Gel Electrophoresis) has been used to study bacterial diversity in soils (Ding et al., 2013; Torsvik et al., 1998; Valánková and Baldrian, 2009; Van Elsas et al., 2002) and during composting (Sampedro et al., 2009).

On the other hand, the measurement of biological activities of soil has become an interesting subject of investigation, not only because of their importance to soil function and structure, but also as changes in biological activity may be used as indicators of soil pollution (Lakhdar et al., 2011). The decrease of some enzyme activities, such as phosphatase and urease, may be related to the presence of heavy metals in MSW and SS composts. The increase of total heavy metal concentration, especially in sandy soils, should be considered as a matter of enhanced risk, as they usually form relatively soluble species in these soils (Kabata-Pendias and Pendias, 2001).

Considering all these issues, in the present work we investigated, on a laboratory scale, the impact on the functionality of a sandy loam soil of biosolids from municipal SS composted with rice husk (Sciubba et al., 2013) at three different and increasing application rates, in order to better understand the response of soil properties to the amendment and underline such effects, with special focus on microbial biomass, basal respiration rate, enzyme activities, total and available heavy metals, and bacterial community structure.

2. Materials and methods

2.1. Soil, biosolids, and chemicals

The biosolids A, B and C were used to amend a cultivated sandy loam soil (*Aquic Xeropsamment*) whose superficial horizon (0–25 cm) was collected and its features are reported in Table 1. The soil samples were taken in a farm located at 44° 06′ 29″ latitude Nord and 12° 31′ 05″ longitude Est (Torre Pedrera, Rimini, Emilia-Romagna region, Northern Italy).

The two biosolids from municipal SS composted with rice husk came from anaerobic (product A) and aerobic (product B) SS (both described in a previous work, Sciubba et al., 2013), whilst the third product (C) was obtained through composting of solid waste, municipal sludge (5% w/w on dry matter) and green manure. A subsample for each biosolid was analysed according to the European methods (EC Regulation 2003/2003), described in Sciubba et al. (2013), and are listed in Table 2.

Total N content, which was employed to establish the application rate, was 1.6%, 2.0% and 2.5% on dry matter, respectively for products A, B and C. The C/N ratio was 13.0 for biosolids A and B, whilst it was 10.3 for C (Table 2).

The stability of biosolids was evaluated by a modified Oxitop® method according to Grigatti et al. (2007). Briefly, an amount of fresh product corresponding to 2.00 g of volatile solids was weighted in a 1 L glass-bottle, with 10 mL of a complete nutrient solution, 10 mL of phosphate buffer pH at 7.0, 180 mL of deionized water and 2.5 mL of ATU (allil-thio-urea) as nitrification inhibitor. The bottle cap was constituted by a soda lime-trap for the adsorption of CO_2 and by the Oxitop® head, able to continuously register the pressure drops due to the respiration of organic material. The system was incubated for 14 days at 25 °C under continuous orbital shaking at 100 rpm. At the end of this period, COU (cumulative oxygen uptake) and OUR (oxygen uptake rate) were calculated. The comparison of the obtained OUR with the reference values of the method (Veeken et al., 2007) allowed us to classify the biosolids according to their stability.

All chemical reagents were purchased from Sigma-Aldrich (Milan, Italy), Carlo Erba (Milan, Italy) and Merck (Darmstadt, Germany).

2.2. Experimental design

The soil, milled and sieved at 2 mm, was pre-incubated at 25 °C and 66% of its water holding capacity (WHC) for 2 weeks. The biosolids, dried, milled and sieved at 0.5 mm were added to the soil at different amounts according to the established dose: zero (no biosolid), 50, 150, and 300 mg kg^{-1} of total N, corresponding approximately to zero (0×), 7.5 (1×), 23 (3×), and 46 (6×) Mg ha^{-1} of biosolid (dry matter

Table 1
Main physical and chemical characteristics of the employed soil.

Texture	Sandy loam soil
Soil classification (soil taxonomy)	*Aquic Xeropsamment*
Sand (g kg^{-1})	790
Silt (g kg^{-1})	100
Clay (g kg^{-1})	110
pH (pH unit)	7.3 ± 0.1
CEC ($cmol_{(+)}$ kg^{-1})	15.3 ± 0.3
Total carbonates (g $CaCO_3$ kg^{-1})	440 ± 8
Active carbonates (g $CaCO_3$ kg^{-1})	75 ± 8
Total organic C (g kg^{-1})	14.0 ± 0.5
Total N (g kg^{-1})	1.38 ± 0.1
C:N ratio	10.1

Data expressed on dry matter, mean ± standard error (n = 3).