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Potential of compost mixed with tuff and pozzolana in site restoration

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ABSTRACT

The present research is aimed at evaluating the potential of mixtures made of different percentages of compost (10%, 20% and 30% by volume) and inorganic waste from extraction activities (tuff and pozzolana) for site restorations. The materials alone and the mixtures were characterised from a geotechnical point of view, in order to determine the optimal percentage to be used. In particular, the oedometric test and the direct shear test were performed. Also the environmental quality of the materials was investigated through chemical characterisation and a leaching test. In addition, a lab-scale seeding test was carried out to assess the potential phytotoxicity of the mixture. Finally, at the end of the experimentation the accumulation of heavy metals in the plants was determined and the plants + artificial soil system underwent a shear stress test.

The presence of compost in the percentages tested did not reduce the mechanical performances of the inorganic residues, guaranteeing good resistance and stability. In fact, the response to oedometric compression, the compression coefficient and the internal friction angle of the mixtures were quite similar to those obtained for tuff and pozzolana alone.

The mixtures selected as optimal from a mechanical point of view (30% by volume of compost and 70% by volume of tuff/pozzolana), did not represent a potential hazard for the environment due to the low content and negligible leachability of heavy metals. In addition, such mixtures can provide a good substrate for revegetation thanks to the high content of organic matter and the absence of phytotoxic effects in the conditions tested.

1. Introduction

Organic waste management in Europe is currently undergoing intense transformations, also in view of an integrated sustainable waste management (ISWM). ISWM refers to a waste management system that best suits the society, economy and environment in a given location (Wilson et al., 2013). The concept of ISWM not only takes technical or financial-economical sustainability into account, but it also includes socio-cultural, environmental, institutional and political aspects that influence overall sustainability of waste management (Vaccari et al., 2013). The European legislation (Directive 2008/98/EC) sets the following waste hierarchy to be applied as a priority order in waste prevention and management legislation and policy: prevention, preparing for reuse, recycling, other recovery (e.g. mass and energy recovery) and disposal. As for biowaste, the Directive encourages its separate collection in view of a future treatment of composting and/or anaerobic digestion.

In such a scenario, the landfill is the residual element of the integrated waste management system (Vaccari et al., 2012). Both European (Directive 1999/31/EC) and Italian regulation (Legislative Decree 36/2003) set some limits to the quantity of biodegradable waste to be landfilled. Thus a large amount of biodegradable waste must be diverted from landfills to other organic waste management practices, where it can be recovered and valorised. A possible strategy could be land application for restoration and rehabilitation of degraded land whose environmental quality has been compromised by industrial and/or raw material extraction activities. For instance, mine sites and abandoned pits are to be re-contoured and topsoil must be replaced. Vegetative cover must be established soon after the end of mining operations to stabilise soils and prevent erosion. Nevertheless, there is a vast amount of degraded land left from extractive activities that requires restoration, to be carried out as cheaply and as effectively as possible. In addition, in both surface and deep mining the original

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vegetation is inevitably destroyed and the soil is usually lost or buried by waste. To achieve a successful restoration, the soil has to be remediated and the vegetation re-established (Bradshaw, 1997).

Organic amendments such as sewage sludge (Debosz et al., 2002; Haering et al., 2000), compost and stabilized organic fraction from municipal solid waste (Brown and Chaney, 2000; Debosz et al., 2002; Giusquiani et al., 1995; Ohsowski et al., 2012) can be successfully used for restoration of abandoned pits or for the reconstruction of topsoil. In fact, such materials can supply sufficient organic matter and nutrients to initiate successful soil rehabilitation and aid vegetation establishment (Cummings et al., 2005; Halofsky and McCormick, 2005a, 2005b; Jochimsen, 2001). Plants have an important role in protecting surface soil from erosion and in allowing the accumulation of fine particles.

Some authors suggested mixing organic with inorganic materials (such as extractive waste) in restoration activities (Boni et al., 2004; Dudeney et al., 2004; Naeth and Wilkinson, 2013), also in order to find a valid market and a sustainable management strategy for such secondary raw materials, that can be considered as artificial soils.

The European legislation (Directive 2006/21/EC) sets the following objectives for extractive waste: to prevent or reduce waste production and its harmfulness, to encourage the recovery of extractive waste by means of recycling, reusing or reclaiming such waste where it is environmentally sound, to ensure a short as well as a long-term safe disposal.

Despite the potential benefits of using organic waste to recover land disturbed by extraction activities, there are some short and long-term risks involved, linked to their land application (San Miguel et al., 2012). Such risks are associated with the presence of pathogens, heavy metals and organic pollutants (Albiach et al., 2000; Ho et al., 2008; Pérez et al., 2007; Sastre et al., 1996). In particular, heavy metals can enter the food chain as a consequence of plants absorption from the soil; alternatively, they can endanger groundwater quality through soil leaching (Alvarenga et al., 2007; Rate et al., 2004). The heavy metal content in organic waste is often higher than in soils, but the concentrations were generally low, with no reason for concern regarding groundwater contamination (Boni et al., 2006; Kaschl et al., 2002). Metal mobility may be affected by the presence of certain organic materials (insoluble, dissolved and colloidal) in compost or sludge. Dissolved and colloidal organic matter may therefore contribute to an increased mobility of trace metals (Boni et al., 2006; Guggenberger et al., 1994; Temminghoff et al., 1998).

There are several strategies to limit heavy metal availability: increasing soil pH and adding organic amendments with a high biological stabilization degree (Abbott et al., 2001; Boni et al., 2006; Brown et al., 2003). Besides, biological stabilization through composting is a successful way to reduce the negative effects of unstable organic matter in the soil, to improve microbial equilibria (Sanchez-Monedero et al., 2004) and to abate pathogens (DeLuca and DeLuca, 1997; Dumontet et al., 1998).

Finally, there are also geotechnical problems to be considered in the land application of organic and inorganic waste. In fact, the stability of the imported artificial soil should be guaranteed. Even if mechanical–biological treatment is able to increase both the oedometric modulus and the angle of shear of organic waste (Kuehle-Weidemeier and Doedens, 2003), compost may present poor mechanical properties in terms of both compressibility and stability with respect to compacted compost (used for landfill covers) and "high friction" rocks (Benson and Othman, 1993; Hemmat et al., 2010; Kuehle-Weidemeier, 2004).

Taking into account the regulatory framework in terms of ISWM and the problems which may arise from the exclusive use of compost in restoration actions, in the present work the suitability of compost mixed with extractive waste for restoration activities was assessed. In particular, granular tuff or pozzolana discarded during the extraction activity in tuff and pozzolana quarries were mixed to compost at different percentages, in order to improve the mechanical and geotechnical characteristics of compost. Tuff and pozzolana are inorganic materials abundantly present and caved in Italy; the great quantity of residues generated by the mining activities is partially recovered as raw material in cement factories, but a large part is just landfilled. The physical, chemical and mechanical characterisation of the materials (i.e. compost, tuff and pozzolana) and the mixtures was carried out. Moreover, an evaluation of their leaching behaviour and a seeding test were performed.

2. Materials and methods

2.1. Materials

The organic material used in the present research is the compost collected from a composting plant with a 88 t/d (tonnes per day) potentiality (about 20 t/d of organic waste from separate collection, 60 t/d of market and food waste and 8 t/d of lignocellulosic waste and green waste). The material was collected after biostabilization (32 d) and maturation (28 days).

Compost is an extremely light and highly compressible material (Boni et al., 2006) even at low vertical loads and is able to get its initial volume as the vertical loads are removed. Due to its poor mechanical characteristics, its exclusive use in restoration activities is not recommended. Thus, in this experimental study compost was mixed with granular tuff or pozzolana discarded during extractive activities in tuff and pozzolana quarries. These extractive wastes are able to provide a sort of stony skeleton and a resistant structure to compost.

The volcanic tuff is an easily workable material, with low specific weight, good mechanical and insulating properties and low thermal conductivity. Thus it represents a widely used construction material. It was also used by Etruscans and Romans for their buildings and monuments (Jackson and Marra, 2006). For this research work, the tuff was collected at a cave located in Riano, near Rome.

Pozzolana is a natural volcanic material that was already used thousands of years ago (e.g. the roman *pilae* of Pozzuoli harbour). The material used in the present experimental activity was collected at the Corcolle cave, near Rome.

The above mentioned materials were mixed, obtaining the mixtures shown in Table 1.

The inorganic materials were previously sieved at 4 mm.

The addition of the organic fraction was limited to a maximum percentage of 30% v/v according to the following criteria:

- Geotechnical: since compost presents scarce mechanical properties (Boni et al., 2006), the criterion was to add a percentage of compost as to enable a potential excessive worsening in the resistance and stability performances of the inorganic granular materials.
- Chemical: the protection of soil, surface water and groundwater must be ensured avoiding possible contamination events due to the leaching of both organic and inorganic pollutants. Thus the limits set by the Italian regulation (Legislative Decree 152/06) must be respected.

Table 1
Percentages (v/v) of the materials used in the mixtures.

	Mixtures					
	T10	T20	T30	P10	P20	P30
Compost	10	20	30	10	20	30
Tuff	90	80	70	–	–	–
Pozzolana	–	–	–	90	80	70