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Influence of organic matter and texture on the compactability of Technosols

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ABSTRACT

The effect produced by adding increasing rates of a municipal solid waste compost on the susceptibility to compaction of three materials of mineral origin was determined. These were quartz sand (85% sand), slate processing fines (78% silt), and commercial bentonite (75% clay), selected due to their highly homogeneous particle size that can provide index information about materials with different textures. The maximum density of compaction of these materials increased in the sequence bentonite < slate processing fines < quartz sand, while the moisture corresponding to the maximum density (critical water content) followed the inverse order. The addition of increasing rates of compost (about 3%, 7% and 14% dry weight) resulted in general in flatter compaction curves and reduced maximum bulk density. The highest rate of compost reduced the maximum density of the quartz sand from 1.88 to 1.33 Mg m^{-3}, from 1.54 to 1.22 Mg m^{-3} for the slate processing fines, and from 1.16 to 1.00 Mg m^{-3} for the bentonite. The addition of compost also increased the critical water content, although only at the highest rates. The effect was more important for the sand, whose critical water content increased from 10.4% to 29.1%; for the slate processing fines it increased from 25.2% to 36.2%; and for bentonite it increased from 38.8% to 52.4%. In general, the extent of the effect of compost addition decreased at the same time as the dominant particle size of the material tested.

1. Introduction

Compaction is the increase in the bulk density of soil which results from loads applied for short periods (Marshall et al., 1996) and is one of the main processes of soil physical degradation (Lal, 2001). It is mainly a result of the development of agriculture (Boels, 1982), and occurs when soil particles are compressed, reducing the pore space between them in response to the pressure exerted by machinery or animals. Compaction (and the associated reduction of pore size) reduces infiltration and increases runoff and erosion risk, can make it difficult or impossible for plant germination and growth, due to the high resistance to penetration and restricts root depth, reducing water and nutrient uptake by plants (Boels, 1982; Lipiec and Hatano, 2003). Several factors influence soil response to compaction, namely moisture, texture, organic matter content and clay mineralogy (Marshall et al., 1996). Among these, the relationship between compactability and organic matter is the most commonly studied, and several authors have demonstrated the inverse relationship between them in a wide range of soils (Aragón et al., 2000; Garcia Pita et al., 1986; Guerif and Faure, 1979; Thomas et al., 1996). According to Soane (1990), this effect is a consequence of the fact that organic matter increases the elasticity and resistance to deformation, thus reducing compactability. Also, organic matter favours aggregation, increasing porosity and decreasing bulk density. This effect of organic matter is very valuable when organic amendments are employed in soils which have suffered severe physical degradation processes. This is relevant not only for agriculture but also during the restoration of mining degraded soils, where compaction of unconsolidated materials is often a problem to plant establishment more severe than chemical limitations such as reduced fertility or potential toxicity (Dollhopf and Postle, 1988). The young soils developed over these materials during restoration are commonly referred to as Technosols, according to the F.A.O. terminology (FAO, 2006). In most cases they are merely a mixture of unconsolidated mineral materials and some (usually low) amount of organic matter, which can come from organic amendments employed during restoration or from the vegetation developed on the materials. The study of the properties and evolution of Technosols is interesting from the point of view of pedogenetic processes, as they can be regarded as the initial stage of soil development. These materials lack the aggregated structure which is the typical feature of natural soils and influences decisively many of their properties; among them are soil mechanical properties such as compactability.

Technosol compactability can be studied in a relatively simple manner by selecting materials with the desired properties among

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the wide range of existing mine wastes. In this sense, the study is simpler than in the case of natural soils, where for example the role of particle size on compaction has been studied indirectly by comparing the properties of several soils with different textures (Aragón et al., 2000; Ekwue and Stone, 1995; Stone and Ekwue, 1993; Zhang et al., 1997), or by studies on the behaviour of granular media (Keller et al., 2013; Philippe and Bideau, 2002). Besides, the study of the effect of organic matter on mechanical properties of natural soil can also be performed by adding different amounts of organic materials to a soil, but it can be argued that this approach does not represent what actually happens in natural soils with the same amount of organic matter. However, this is not the case for Technosols, which are usually built by the addition of organic amendments to mineral wastes, and where therefore the real conditions can be adequately simulated.

With the objective of determining the mechanical behaviour of Technosols at the first moments of restoration, we studied the compactability of three materials with a highly homogeneous particle size distribution, each one corresponding to one particle size class (sand, silt, clay), and their response to the addition of organic matter at different rates. Compactability was determined using the Proctor test, which is widely used for the study of soils and unconsolidated materials, in order to predict the stability of buildings or to determine the resistance of agricultural soils to compaction (Marshall et al., 1996).

2. Materials and methods

2.1. Materials

The following materials of contrasting texture were used: quartz sand (A), slate processing fines (L), and bentonite (B). The quartz sand was obtained from the quartz exploitation of the Pico Sacro Serrabal (A Coruña, Spain). Slate processing fines are the mineral residue produced during the sawing of slate blocks in the processing plants. They were supplied by the company IROSA, located in Valdeorras (NW Spain). Bentonite is a commercial mixture of smectite clay supplied by Minas de Gador S.L. (Almería, Spain). The texture of the materials was determined by the pipette method, and pH in aqueous suspensions 1:2.5 m/v, following the procedures described by Guitián and Carballas (1976).

The compost used was provided by the composting plant Complexo Medioambiental do Barbanza (A Coruña, Spain). It is an aerobic compost obtained from source-separated organic fraction of municipal solid waste. The main properties of the compost, determined according to UNE standard methods for soil amendments and growing media (AENOR, 2001a, 2001b, 2001c), were the following: pH 8.7; total organic matter: 380 g kg^{-1}; EC$_{1:5}$ 5.1 dS m^{-1}.

Each material was mixed with 10%, 25% or 50% compost (moist weight, equivalent to approximately 3%, 7% and 14% dry weight), in order to obtain the mixtures A90, A75 and A50 (quartz sand blended with 10, 25 and 50% compost, respectively), L90, L50 and L75 (slate processing fines blended with 10, 25 and 50% compost, respectively), and B90, B75 and B50 (bentonite blended with 10, 25 and 50% compost, respectively).

2.2. Methods of analysis

The compaction curves were determined following the standard Proctor test (ASTM, 1992), which allows to study compactability over a range of moistures under a standardised dynamic load, and provides useful parameters for comparing different materials, including maximum bulk density and critical water content at the maximum. The test was performed with a delay of at least 24 h after the preparation of the mixtures. Subsamples of about 2.5 kg were spray-moisturised in order to reach eight different water contents. Following the method, amounts of soil from these homogenised wet subsamples were compacted in three layers in a compaction chamber, volume 0.911 · 10^{-3} m^3. Each layer received 25 blows of a 2.5 kg falling hammer from 0.305 m height. The energy density was 593.7 kJ m^{-3}. The weight of the wet compacted soil in the chamber was determined. Then the samples were dried in an oven at 105 °C for 24 h, and weighed again to estimate the moisture content and dry bulk density. The parameters obtained from the curves, which relate bulk density with moisture content, are the maximum bulk density, and the critical water content for compaction.

To determine the porosity (p, in % v/v) of the samples at the compaction maximum, their particle density (ρ_p) was first determined by the pycnometric method after saturating the samples with toluene (Guitián and Carballas, 1976), and then their porosity was calculated using the maximum bulk density (ρ_b) as follows

$$p = \left(1 - \frac{\rho_b}{\rho_p}\right) \cdot 100$$

Regression analyses of the results were run using the R statistical package for MacOSX (R Development Core Team, 2011).

3. Results and discussion

The mineral materials employed showed very homogeneous particle size distributions (Table 1), with the sand fraction (>50 μm) as the main one for the quartz sand, the silt fraction (2–50 μm) as the main for the slate processing fines, and the clay fraction (<2 μm) as the main for the bentonite. The high homogeneity of the size distribution of these materials makes us think that we could reasonably use these materials as a guide for the behaviour of the different size fractions of Technosols, although with some cautions for clay soils, whose behaviour may vary if clays of different mineralogy exist.

Regarding the compaction curves of the three soil-like materials (Fig. 1), differences were shown which can be attributed to their contrasted textures. The maximum bulk density of the materials increased following the sequence: bentonite < slate processing fines < quartz sand, whereas the critical water content followed the inverse order. This agrees with what has been observed in soils, where the susceptibility to compaction depends largely on its texture. For example, in coarse textured soils, with high proportions of sand, the critical water content is usually low, and maximum bulk density high; but as the texture becomes finer, the values for the maximum bulk density decrease and the critical water content increases (Marshall et al., 1996).

The addition of increasing rates of compost decreased bulk density of the materials (Fig. 1), as expected, since bulk density of compost is much lower than that of mineral materials, what is in fact a dilution effect, and also due to the higher degree of elasticity of organic matter under compression forces compared to mineral particles (Soane, 1990). Compost reduced the maximum density of compaction for all the materials proportionally to the rate employed (Table 2, Fig. 2). The highest rate of compost reduced the maximum bulk density of the quartz sand from 1.88 to 1.33 Mg m^{-3}, for the slate processing fines from 1.54 to 1.22 Mg m^{-3}, and for the bentonite from 1.16 to 1.00 Mg m^{-3}. Several authors have noted the reduction in bulk

Table 1
Particle size distribution and pH of the soil-like materials employed.

	Quartz sand	Slate processing fines	Bentonite
pH	5.7	8.4	10.3
Sand (%)	85	11	7
Silt (%)	7	78	20
Clay (%)	8	11	73
Texture	Loamy sand	Silt loam	Clay