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# BULK DENSITY AND AGGREGATE STABILITY ASSAYS IN PERCOLATION COLUMNS*

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The restoration technologies in areas degraded by extractive activities require the use of their own mine spoils. Reducing deficiencies in physical properties, organic matter, and nutrients with a contribution of treated sewage sludge is proposed. This experiment was based on a controlled study using columns. The work was done with two mine spoils, both very rich in calcium carbonate. Two sewage sludge doses were undertaken (30,000 and 90,000 kg/ha of sewage sludge) in addition to a different mine spoils used as restoration substrates. The water contribution was provided by a device that simulated short duration rain. The leached water was collected 24 hours after the last application. The experiment saw the bulk density decrease and the aggregate stability increase, thereby improving the structure. The improved soil structure decreases its vulnerability to degradation processes such as erosion and compaction.

***Key words***: mining areas, reclamation, sewage sludge, soil quality, mine spoils.

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**Introduction.** The restoration of extensive areas degraded by mining activities, the use of their own waste materials is required [1-4]. These materials do not possess the necessary fertility to ensure a successful process of restoration (implementation of adequate plant cover). Therefore, it requires the addition of organic amendments to achieve efficient substrate [5]. The obligation to restore abandoned mine and the correct application of biosolids is guaranteed by the legislation on waste management, biosolids and soil conservation [5]. Technosols are one of the latest additions to the World Reference Base for Soil Resources [6]. This new reference soil group contains a large range of artifacts and materials of natural and anthropic origin. They include a variety of refuse-based soil-like mine spoils, landfills, cinders or sludge, whose properties and pedogenesis are dominated by their technical origin [7]. An adequate technosol selection, based on its nature and intrinsic properties, can constitute a valuable and cost-effective solution for soil remediation and waste management [7]. Sewage sludge application in restoration has demonstrated its efficiency in previous studies. The use of treated sewage sludge can be a guarantee of success in the restoration of areas affected by mining activities.

There are lots of studies on soil fertility and the risk of groundwater contamination [8-9]. However, there are few studies about the improvement of the physical properties (bulk density and aggregate stability) of technosols design for ecological restoration of quarries. This paper shows different and alternatives methodologies for determining these properties and the main results obtained in a realistic case of study.

**Materials and methods.** *Technosols design.* The experimentation was carried out on a controlled study using columns. PVC pipe with a 10.5-cm interior diameter cut into 15-cm length pieces was used to make them. Two of these pieces were then stacked to construct each of the fifteen 30-cm tall columns. Two treatments and a control were applied, which depended upon the quantity of sludge applied (Table 1). The sewage sludge was applied on the surface and mixed with the soil, simulating a plowing or tilling action, producing a homogenous mixture within the uppermost 15 cm of soil.

The experiment was carried out using two different limestone quarry spoils, both very rich in calcium carbonate. The first, of poor quality, originates from the crushed limestone (*Z*). It is composed of coarse materials (up to 75 % by weight) and sand. The other tested waste material comes from the extraction of limestone. This waste was formed by the levels of interspersed non-limestone materials and remains of stripped soils (*D*). This usually has high heterometric stoniness (up to 60 %), and is richer in clays (approx. 25 %). These materials were amended with the biosolid. The characteristics of the mineral substrata employed appear in Tables 2 and 3.

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*Table 1*

**Experimental design and identifying symbols**

| Symbol | Material contents |
|---|---|
| $Z_0$ | 30 cm column filled with limestone spoils |
| $D_0$ | 30 cm column filled with stripped soil |
| $(Z+D)_0$ | 30 cm column filled from 0-15 cm with stripped soil and 15-30 cm with limestone spoils |
| $D_3$ | 30 cm column filled with stripped soil. Sewage sludge dose (30,000 kg/ha) homogenous mixture first 15 centimeters. Three replications |
| $D_9$ | 30 cm column filled with stripped soil. Sewage sludge dose (90,000 kg/ha) homogenous mixture first 15 centimeters. Three replications |
| $(Z+D)_3$ | 30 cm column filled from 0-15 cm with stripped soil and 15-30 cm with limestone spoils. Sewage sludge dose (30,000 kg/ha) homogenous mixture first 15 centimeters. Three replications |
| $(Z+D)_9$ | 30 cm column filled from 0-15 cm with stripped soil and 15-30 cm with limestone spoils. Sewage sludge dose (90,000 kg/ha) homogenous mixture first 15 centimeters. Three replications |

*Table 2*

**Particle size distribution in the substrata used in the experiment**

| Texture | Clay (%) | Silt (%) | Sand (%) |
|---|---|---|---|
| *Z* | 15.40 | 16.00 | 68.60 |
| *D* | 21.37 | 26.00 | 52.63 |

*Table 3*

**Characteristics of the substrata used in the experiment**

| Parameter | *Z* | *D* |
|---|---|---|
| pH | 8.30 | 8.90 |
| EC μS/cm (25 ºC) | 259.20 | 58.32 |
| OM (%) | 0.63 | 0.37 |
| P (mg/kg dry matter) | 2.05 | 2.10 |
| Ca (g/kg dry matter) | 3.40 | 3.36 |
| N (%) | 0.03 | 0.02 |
| $CaCO_3$ (%) | 45-75 | 55-70 |

The biosolid used in this experiment comes from a wastewater treatment plant located near Alicante (SE, Spain). Prior to the composting process, the sludge needs to be mixed with a bulking agent, a supporting structure that favors aeration, absorbs humidity, and furthermore contributes carbon. Sewage sludge composition is showed in Table 4.

*Table 4*

**Sewage sludge composition from the Aspe wastewater treatment plant**

| Parameter | Value |
|---|---|
| Organic C (%) | 46.4 |
| Kjeldahl N (%) | 4.7 |
| P (%) | 0.28 |
| K (%) | 0.03 |
| Ca (%) | 0.11 |
| Mg (%) | 0.08 |
| Fe (g/kg dry matter) | 6.48 |
| Cu (mg/kg dry matter) | 298 |
| Zn (mg/kg dry matter) | 868 |

*Irrigation.* In order to establish the closest parallels between real conditions and those of the experiment, the soil contained in the columns was irrigated (8 applications) with tap water. The first five irrigations occurred every two weeks and the last three once per month. The contribution of water was provided by a device that simulated short rainfall or a flood irrigation system that covered the surface and then percolated into the soil.

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**Determination of some physical properties of the substratum.** *Bulk density.* Measuring the bulk density in every case is important due to its great variability. Determining the bulk density may be done by different methods, but preferably two are used. The best way to determine the bulk density is by taking a fixed volume of undisturbed soil and weighing it once dry, after heating it at 105 °C until it reaches a constant weight. To do this, a metallic cylinder with a volume close to 100 mL is usually used. Once it is full and flush at both ends, the contained soil is extracted. Its volume corresponds to that of the cylinder and therefore known; it is then dried and weighed. The density is determined by the ratio between the weight obtained and the corresponding volume. The main drawback to this system is the presence of stones, so this can only be used in non-stony soil, which unfortunately, is less common. In this case, using another system is more convenient, one that is less precise but easier. It involves taking aggregate from the soil, as large as possible, drying it, and weighing it to learn its mass. A string is tied to it and it is submerged into molten paraffin to coat and waterproof its surface; once solidified, it can be weighed once again. The wax-coated aggregate is introduced into a graduated cylinder containing a known quantity of water. The volume gain of the water as a consequence of the introduction of the aggregate corresponds to its volume. This way, the two parameters necessary for the density calculation are learned. Although the paraffin layer is very thin and its volume negligible, it can be estimated based on its density and the weight increase undergone by the aggregate following the waterproofing process. The main drawback of this method is that it cannot specify the volume of the cracks and interped voids. However, by wetting the soil, they all disappear; this serves to determine the behavior of moist soil.

*Aggregate stability.* Determining the percentage of stable aggregates in the soil was performed by an artificial rain simulator according to the method described by Roldán [10].

**Results and Discussion.** The bulk density and percentage of stable aggregates have been determined as physical properties that can be modified following the application of organic amendments to the soil like is sewage sludge. Bulk density is defined as the ratio between the mass of the oven dry soil and the overall volume, which includes the volume of the particles and the porous space between them. It is dependent upon the soil particle densities (sand, silt, clay, and organic matter) and their type of packaging. Mineral particle densities are found within the range of 2.5 to 2.8 g/cm$^3$, while organic particles are usually <1.0 g/cm$^3$ [11]. The bulk density is a dynamic property that varies along with the structural conditions of the soil. It can serve as an indicator of the compaction and the restrictions to root growth [11, 12]. With respect to the substrata without amendment, aggregate ($Z_0$), degraded ($D_0$), and a mixture of aggregate and degraded $(Z + D)_0$, the results indicate that substratum $Z_0$ has the lowest bulk density, logically due to its much thicker texture that is going to favor the availability of air voids in the column, decreasing the mass/volume ratio. As seen in Fig. 1, the sludge application decreases the bulk density in the distinct substrata tested with respect to the control, with the decrease being greater the greater the sludge dose.

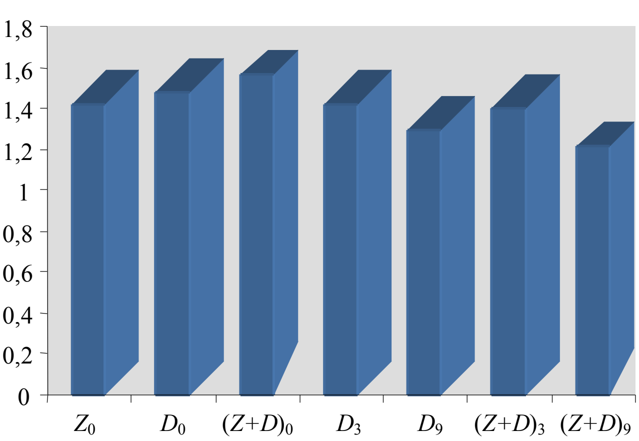


Fig. 1. Bulk density (g/cm$^3$) for the different substrata used

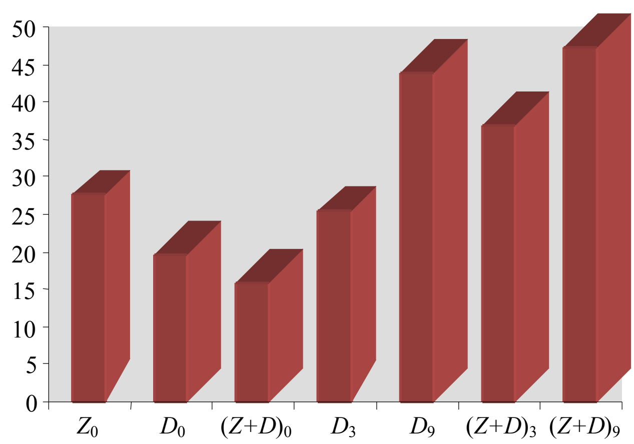


Fig. 2. Aggregate stability (%) in the different substrata used

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The organic content of the applied residue is going to improve the substratum structure by favoring the formation of pores that contribute to the bulk density decrease. High doses of sludge (90.000 kg/ha) obtain a bulk density inferior to 1.4 g/cm$^3$, a value recommended by the USDA [11] for sandy loams and loams (Table 5). Bulk density values greater than 1.6 g/cm$^3$ can affect root growth and even restrict it (Table 5).

*Table 5*

**General relationship of soil bulk density to root growth based on soil texture. Source: USDA (1999). Soil Quality Test Kit Guide**

| Soil texture | Ideal bulk densities (g/cm$^3$) | Bulk densities that may affect root growth (g/cm$^3$) | Bulk densities that restrict root growth (g/cm$^3$) |
|---|---|---|---|
| Sands, loamy sands | <1.60 | 1.69 | >1.80 |
| Sandy loams, loams | <1.40 | 1.63 | >1.80 |
| Sandy clay loams, loams, clay loams | <1.40 | 1.60 | >1.75 |
| Silts, silt loams | <1.30 | 1.60 | >1.75 |
| Silt loams, silty clay loams | <1.40 | 1.55 | >1.65 |
| Sandy clays, silty clays, some clay loams (35-45 % clay) | <1.10 | 1.49 | >1.58 |
| Clays (>45 % clay) | <1.10 | 1.39 | >1.47 |

Aggregate stability is a measure of the vulnerability of soil aggregates exposed to external disruptive forces. Soil aggregates consist of diverse particles that are bound to one another [10]. Aggregates that resist the forces of water are called water-stable aggregates (WSA). In general, the higher the percentage of stable aggregate, the lower the soil erodibility. Soil aggregates are products of the soil microbial community, the organic and mineral components in the soil, the nature of the plant communities on the surfaces, and the ecosystem history [11, 12]. Soil aggregation can vary over certain periods of time, such as a season or a year [10]. Aggregates can form, disintegrate, and re-aggregate periodically. Aggregates improve soil quality by: i) protecting the organic matter trapped in the aggregates from exposure to air and microbial decomposition, ii) decreasing soil erodibility, and iii) increasing the movement of water and air (aggregates increase the amount of large pore space), thus improving the physical environment for root development and the habitat for soil organisms [11, 12].

Figure 2 shows that the control substrata used have a relatively low percentage of stable aggregates. The application of sludge increases the percentage of stable aggregates, with this increase much larger for the greater application rate (90.000 kg/ha). The increase of organic matter in the soil will improve numerous properties thereof, among which all those related with the structure, like bulk density, aggregate stability, porosity, etc., can be highlighted. The improved soil structure decreases its vulnerability to degradation processes such as erosion and compaction. Nevertheless, no cases reached the values recommended by the USDA (1999) for soils with a clay fraction percentage around 15 %, which was situated between 65-70 % (Table 6).

*Table 6*

**Percentages of water-stable aggregates determined by clay and organic matter contents. Source: USDA (1999). Soil Quality Test Kit Guide**

| Organic matter (%) | Water-stable aggregates (%) | Clay (%) | Water-stable aggregates (%) |
|---|---|---|---|
| 0.4 | 53 | 5 | 60 |
| 0.8 | 66 | 10 | 65 |
| 1.2 | 70 | 20 | 70 |
| 2 | 75 | 30 | 74 |
| 4 | 77 | 40 | 78 |
| 8 | 81 | 60 | 82 |
| 12 | 85 | 80 | 86 |

Aggregate stability values are based on 519 soil samples from the arid, semi-arid, and sub-humid regions of the United States and Canada.

Considering the percentage of organic matter in the substrata, the aggregation percentage should have been 53 % for the case of $D_3$ and 70 % for the case of $D_9$ [11].

**Conclusions.** The experiment saw the bulk density decrease and the aggregate stability increase, thereby improving the structure. During our experiment, the values recommended by USDA were not reached. It must be kept in mind that aggregate stability should increase over time.

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