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A novel green technology for a safe and eco-friendly long-term slope landfill aftercare

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ABSTRACT: Long-term slope landfills pose nowadays a serious social, ecological and economical problem. Long-term landfill management issues are problematic when durability and stability are not guaranteed. In the last decades, much attention has been devoted to the so-called Nature Based Solutions (NBSs), but these solutions often turn out to be problematic as traditional plant species are not strong enough to survive in hard climate conditions, sterile and/or contaminated soils. Among the NBSs for long-term aftercare, the Deep Rooting Plant solution, DRP, proposed by Prati Armati®, allows to operate in any condition. The present work promotes this innovative strategy, showing the benefits provided in terms of capability to grow, environmental impact and economic point of view with respect to different solutions traditionally considered for the application in long-term slope landfill aftercare.

Keywords: Slope landfill; long-term waste aftercare; sustainable maintenance; deep-rooted vegetation; nature-based solutions; circular economy.

1. INTRODUCTION

Proper waste disposal strategies and good practices for the management of exhausted slope landfills are only recently spreading throughout the civil society. In Italy, for example, until the 1970s municipal solid waste (MSW) was collected in an undifferentiated manner and disposed of also in uncontrolled landfills. Recycling and material recovery practices involving separate collection only began to spread in the country in the late 1990s. The basic principles for waste management were established in Italy by Ronchi's decree (law 22/1997), which introduced rules for: reducing waste production, encouraging recovery and recycling, increasing environmental awareness and fostering active collaboration between companies and municipalities (Massarutto, 2010).

This long-lasting lack of both culture and regulations has left a huge number of illegal and uncontrolled slope landfills all along the national territory, which now poses serious ecological end environmental issues to be dealt with. In fact, other than typical aftercare strategies and standards for long-term landfill management (e.g., Laner et al., 2012), emergency safety measures may be necessary for uncontrolled or abandoned slope landfills, especially when their durability and stability are not guaranteed.

Traditional solutions (Manassero et al., 2000) include mineral liners (e.g., Compacted Clay Liners, CCL. Solution 1 in Figure 1) and geosynthetic liners (e.g., composite barriers consisting of mineral liners or Geosynthetic Clay Liners, GCL, placed in close contact with a geomembrane, GM; Solution 2 in Figure

1). Much attention has been paid recently to the application of Nature Based solutions (NBSs) for old slope landfill restoration (e.g., Remon et al., 2005) especially by sowing and growing a vegetation layer covering the waste materials. However, such restoration technique often turns out to be quite tricky, mainly because the traditional plant species do not develop a vigorous root system in any context; moreover, these species do not always prove capable to germinate, survive and grow in hard climate conditions, sterile and/or contaminated subsoils (Tordoff et al., 2000; Mendez & Maier, 2008; Shahsavari et al., 2013). To solve such issue, over the years several techniques have been developed for soil renaturation with particular reference to tough geo-chemical context.

2. PROPOSAL OF A NOVEL TECHNIQUE AMONG NATURE BASED SOLUTIONS (NBSs)

Among the NBSs for long-term landfill aftercare, an emerging innovative technology is presented herein that adopts only natural herbaceous perennials plants with deep rooting system (Deep Rooting Plant solution, DRP, proposed by Prati Armati®; Solution 3 in Figure 1); such technique allows to operate in areas where climatic conditions are generally considered prohibitive for the development of vegetation, e.g., barren lands, altered or fractured rocks, soils treated with addition of lime up to 5% by weight, soil polluted by waste, hydrocarbons and heavy metals (Bradshaw et al., 1978; Kavamura e Esposito, 2010) in concentrations up to 10 times higher than the upper limits admitted by law in industrial areas.

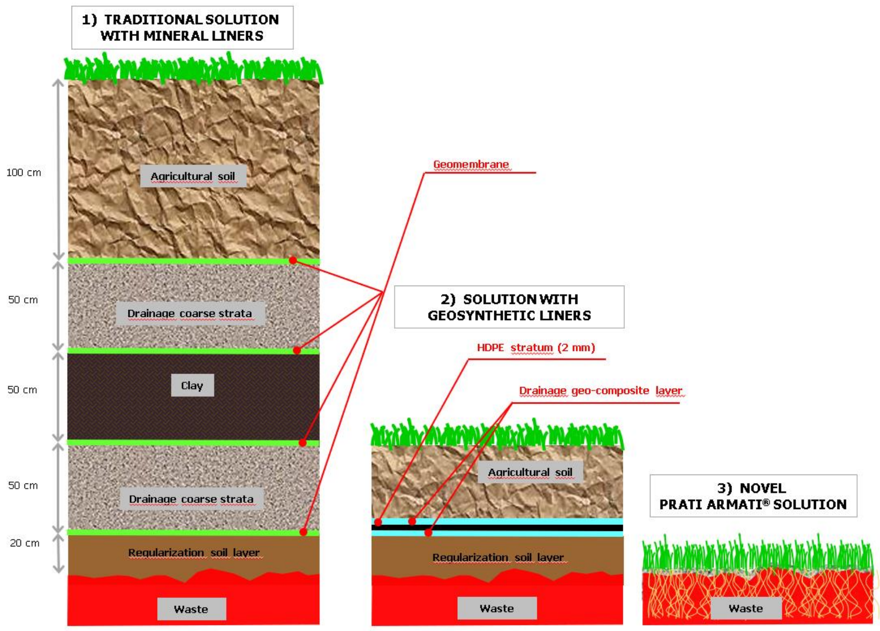

Figure 1: Schematic representation of the three different solutions here investigated.

This natural solution, often framed within bio-engineering remediations, has already proved effective in reducing weather-induced soil erosion.

If the equation to calculate USLE (Universal soil loss equation), A, is written as:

$$A = R \times K \times LS \times C \quad (1)$$

where:

A – Annual soil loss,
R – Rainfall erosivity factor
K – Soil Erodibility Index

LS – Slope Factor, which is the combination of the slope steepness (S) and slope length (L)

C – Cover factor, which represents the protective coverage of canopy and organic material in direct contact with the ground,

it can be observed that the novel strategy intervenes on the C factor, which is a fundamental part of the equation when speaking about the vegetation layer covering. The C factor is important because if the selected species are able to grow and resist to prohibitive condition, this factor reduces to values close to zero and the loss of soil is stopped. Otherwise, if the vegetation layer cannot produce such an impact on the C factor, the soil loss continues, with potential consequences also on diffusion of pollution and leachate in the deepest soil layers.

Making reference to real monitored case studies of slope landfills (e.g., Figure 2), the differences between the novel DRP solution and the traditional strategies presented in Figure 1 have been investigated in this work, in terms of environmental and economic impact, as well as hydro-geotechnical behaviour in the long-term.

Figure 2. Case study of a 20000 m^2 slope landfill in Sicily (PA): before and after installation of the DRP solution (Solution 3, in Figure 1).

3. ENVIRONMENTAL FOOTPRINT OF THE PROPOSED SOLUTION

As first, the environmental impact of the three different solutions is analysed in terms of Natural resource consumption (Cumulative Energy and Exergy Demand indicators), and pollutant emissions (Vanone e Summa, 2012), making use of the Life Cycle Assessment, LCA, framework (Rocco et al., 2016), relying on Ecoinvent database.

Results show that the DRP solution is less impacting from one to two orders of magnitude compared to the other solutions. In **Errore. L'origine riferimento non è stata trovata.** synthetic results of both the energy consumption and of the CO_2 emission corresponding to each of the three solutions in Figure 1 are given.

Table 1. Comparison of the Energy consumption and the CO_2 emission for the different solutions in Figure 1.

Solutions	Energy consumption [GJ]	CO2 emission [ton]
Traditional solution with mineral liners (1)	15991	853
Solution with geosynthetic liners (2)	3954	143

Deep rooting plants solution (3)	102	5

Other than the Energy consumption and the CO_2 emission, also the principal pollutant emissions of the 3 solutions have been investigated in this work, as shown in Table 2. The innovative solution proposed can reduce pollutant emissions to extremely low quantities.

Table 2. Comparison of the SOx, PM, NOx, CO emission for the different solutions in Figure 1.

Solutions	SO_x [kg]	PM [kg]	NO_x [kg]	CO [kg]
Traditional solution with mineral liners (1)	1049	769	3453	1376
Solution with geosynthetic liners (2)	291	166	453	536
Deep rooting plants solution (3)	30	9	19	9

Table 1 and Table 2 show that on the point of view of the pollution emissions, solution 1 and solution 2 are very problematic with respect to the recent global tendency to reducing the environmental impact. Also, the peculiar vegetation type adopted in the NBS technique proposed by Prati Armati® has the advantage to absorb in the optimal condition up to 40 ton/ha/year of CO_2, against about 8 ton/ha/year of traditional herbaceous species (FAO).

4. GEOTECHNICAL IMPLICATIONS OF THE DPR SOLUTION

As for the geotechnical behaviour of the investigated strategies, the relevant slope angle of such slope landfills usually increases the associated landslide risk; the installation of either solution 1 or solution 2 in Figure 1 imposes a relevant load on the inclined ground surface. This often compromises the slope stability, inducing failures which may involve sliding surfaces along the weakest interface, which usually is the contact surface between the geosynthetic layer and the soil (Pasqualini et al., 1993a, b; 1996). Such stabilizing load is removed if solution 3 is adopted. Furthermore, recent studies in the literature have demonstrated the beneficial effects the root system may produce on the soil-vegetation system: increase of the composite (root-soil) shear strength (Bischetti et al., 2001; 2009); increase of the transpiration flux, which in turn has a positive impact on soil strength (e.g., increase in soil cohesion). From the hydrological point of view, Solution 3 has been found capable of strongly protect slopes due to the vegetation layer covering especially in presence of slopes with relevant inclinations.

5. ECONOMIC COSTS OF THE DPR SOLUTION

As regards the economic side, both solutions 1 and 2 generally prove to be very expensive. If the regional price list of Basilicata region (Prezzario Regionale Basilicata, 2010) is taken as an example, an estimation of the expenses required by the two solutions can be made: the materials involved, the related logistics and all the time-consuming operations have to be taken into account, not to mention the high realization risk the workers have to deal with.

On the whole, this results in costs of about 1.113.300 €/ha and about 717.500 €/ha for solution 1 and 2, respectively.

On the other hand, Solution 3 requires cheaper construction activities, combined with shorter realization timing, resulting in a cost estimation of about 235.000 €/ha. Moreover, it is worth mentioning the lower risk workers are exposed to (e.g., hydroseeding may be also carried out by using helicopters).

In Table 3 the costs are synthetized for each solution.

Table 3. Comparison of costs for the different solutions in Figure 1.

Solutions	**Regularization soil layer**	**Drainage coarse strata**	**Clay**	**Agricultural soil**	**Geomembrane**	**Drainage geo-composite layer**	**HDPE stratus 2 mm**	**Traditional hydroseeding**	**DPR system**	**Total cost For 10.000 m²**
Traditional solution with mineral liners (1)	29,25 [€/m³]	36,91 [€/m³]	26,91 [€/m³]	29,25 [€/m³]	7 [€/m²]	/	/	3,12 [€/m²]		1.113.300,00 €
Solution with geosynthetic liners (2)	29,25 [€/m³]			29,25 [€/m³]	/	14,52 [€/m²]	19,11 [€/m²]	3,12 [€/m²]		717.500,00 €
Deep rooting plants solution (3)	/	/	/	/	/	/	/	/	23,50 [€/m²]	235.000,00 €

6. CONCLUSIONS

In the previous sections, the numerous benefits deriving from the application of the innovative technology proposed with respect to traditional more common approaches have been discussed, namely the reduction in pollutant emissions, the positive impact on slope stability, the significant decrease in cost estimation.

Finally, both solutions 1 and 2 need recurring and demanding aftercare maintenance, which adds both economic and environmental costs. Such maintenance is not required when adopting solution 3, which is a rather self-repairing intervention, allowing for a recovery of the naturalistic landscape.

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