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Environmental Response to the Use of Sewage Sludge on European Mediterranean Degraded Soils

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ABSTRACT

Soils in the Mediterranean region have a low resilience to disturbances and are now extensively degraded both physically and bio-chemically. Inappropriate agricultural practices, exacerbated by other natural and human induced perturbations such as increased drought and forest fire occurrence have caused soil impoverishment and the subsequent abandonment of agricultural land in many regions. One of the most promising approaches to soil rehabilitation on such land is the application of organic wastes. Organic refuses, such as sewage sludge, are commonly used on agricultural land, but are increasingly considered for the reclamation of degraded land and mine deposits. The positive effect of such organic matter, nutrient and microorganism additions are now widely recognised. Very

little, however, is known about the detrimental effects of such treatments. The impacts of phytotoxins, heavy metals, salts (especially sodium) and hydrocarbons added via organic wastes are not well enough understood to be thoroughly considered before application. Potential detrimental impacts include accumulation of metals, phosphorus, nitrogen, and resilient aliphatic hydrocarbons, leading to toxicity, nitrate influxes to the groundwater and changes in soil wetting properties.

Keywords: sewage sludge, degraded soils, soils recovery, semi-arid conditions, European soils.

INTRODUCTION

Many areas in Mediterranean environment exhibit serious soil degradation, due to natural and anthropogenic disturbances such forest fires[1], mining[2], abandoned degraded agricultural soils and salinization by irrigation with low quality water[3]. A particularly low resilience to such disturbances due to their low organic matter levels has exacerbated this trend[3]. Attempts to restore degraded soils need to consider physical, chemical and biological properties[4,5]. Soil organic matter plays an important role in all of these soil parameters[6,7]. Addition of organic matter is therefore one of the most promising strategies in restoring degraded soils and the regeneration of ecosystems.

Organic matter in the form of wastewater sludge (composted or not) has for many years posed considerable disposal problems[8-10]. Moreover, land application of organic wastes could contribute to carbon sequestration in soils[11]. However, sewage sludge often contains relatively high concentrations of certain heavy metals, N and resilient hydrocarbons. For instance, the concentration of heavy metals in wastewater sludge is often closely associated with the level of industrialization in the region served by the municipal wastewater treatment facility. When sludge from plants treating industrial wastewater is applied to land, the soil's ability to adsorb heavy metals and accumulate them in the root zones of plants raises critical questions regarding the impact of more soluble metals on biological activity in soils. In European countries, where environmental awareness is evolving alongside rapid industrialization, the number of wastewater treatment facilities is increasing, leading to a significant rise in the volume of sewage sludge generated as secondary waste. This escalation in secondary waste necessitates research into the challenges, characteristics, and potential applications of such material.

Several researchers have studied the application of water treatment sludges (WTS) to soils in general[12-18]. They have identified some of the effects of WTS on the physical characteristics of the soil and on the availability of nutrients for plants that are grown on the treated soils. However, previous studies have not provided sufficient information that allows a thorough evaluation of the positive and detrimental effects of the application of WTS to soils. This knowledge gap extends even to the chemical characteristics of WTS, for which little published data are available. In agricultural soils, the use of sewage wastes is a well-established practice, which has been studied in some detail during the past years. Sludge applications are frequently analysed with respect to the chemical fertility and the amelioration of the physical properties but few evaluate the full environmental impact of such applications to a wider range of soils including also degraded land. Through the integrated work and research between different groups that can give a global vision of the beneficial and detrimental effects we can indeed advance the knowledge of using sewage sludge applications in restoring degraded soils, however, systematic research has not been carried out to address this matter. It is timely to evaluate and promote the rehabilitation of degraded land characterized by eroding soils, acid soils, saline soils and soils affected by heavy metal contamination (e.g.: mining soils). It is, however, very important first to understand the relation between chemical fertility, physical properties and biological activity for a complete rehabilitation of a soil.

Table 1: Data corresponding to target European market (FAO database).

Specific market	Tm	Euros
Agriculture Amended	17.340.430	1.127.100.000
Soil rehabilitation	346.800	22.542.000

Germany, France and Spain will probably still be the countries which use the highest amounts of sewage sludge in agriculture (> 600.000 t/year), with Ireland and Finland reusing the highest percentage of their sludges in agriculture (>73 %). The data provided in Table 1 and 2 demonstrate a very considerable market potential for the use of organic waste in land rehabilitation.

Table 2: Some EU member state sewage sludge production in a standard year.

EU State	Population (million)	Sludge Production (tons dry matter)
FINLAND	*5.1*	*160*
IRELAND	*3.7*	*113*
SPAIN	*42.4*	*1088*
GREECE	*10.5*	*99*
AUSTRIA	*8.1*	*196*
FRANCE	*60.4*	*1172*
POLAND	*10.8*	*359*
DENMARK	*5.3*	*200*
ITALY	*57.6*	-
GERMANY	*82.0*	*2786*
BELGIUM	*10.2*	*160*
NETHERLANDS	*15.8*	*401*

Authors believe that appropriate sewage sludge applications can provide a sustainable solution to both the increasing problems of sewage sludge recycling and rehabilitation needs of degraded land. A key problem has been the lack of knowledge and cooperation between researchers and the industry within this sector. To address this problem, we propose a project builds on the close co-operation of different research institutions and the industry at the European level. Thus, the objectives of this research were (i) to determine the composition of WTS, (ii) to evaluate sludge/soil interactions, (iii) to evaluate de response of sewage sludge application in degraded soils in European Mediterranean area.

SOIL/LAND TYPES SUITED TO RESTAURATION WITH ORGANIC WASTES

Mining Soils

Quarrying activities such as limestone extraction, entail significant visual impacts and degradation problems as a result of soil depletion and deep alteration of the original topography. These areas are at high risk of erosion due to removal of vegetation. Usually, the material used to restore the landscape (derived from extraction holes, etc.) lacks key physical, chemical and biological characteristics. The application of organic amendments could improve this material under the point of view of soil quality, enhancing the possibility to introduce vegetation[19].

Figure 1: Limestone extraction in Pinoso (Alicante, Spain).

Burned Soils

Forest soils can suffer serious alterations in physico-chemical properties produced by wildfires[20,21], which vary with the type of fire, fire severity, climate conditions, soils conditions and topography[22,23]. In Mediterranean environments the erosion after forest fires is one of the main causes of soil degradation, associated with the relatively long period of vegetation regeneration[24]. Rapid restoration of the natural vegetation is important in reducing losses from erosion[25-27]. The use of organic additives can help to restore the organic matter pool depleted by oxidation during burning.

Abandoned Degraded Agricultural Soils

In semiarid areas, socio-economical changes during the last decades have promoted a situation of abandoned agricultural land, particularly in areas with soils low in organic matter content. In these areas the erosion risks are elevated due to rains in autumn period with a high energy[28]. An improvement of soil characteristics by organic refuse application as sewage sludge[1] in these cases is very promising in reducing soil losses, and to prepare the soil for reforestation, which is the preferred land use in many of these areas[13].

Figure 2: Abandoned agriculture soils in Cox (Alicante, Spain).

Salinized Soils

The irrigation of soil with low quality water (i.e. with high salinity levels) is common in semiarid areas. The salinity can be a limitation factor in biomass production and can induce changes in soil structure reducing aggregate stability and increasing soil erodibility. Organic wastes can improve aggregate stability and increase hydraulic conductivity that can be a way to produce a better situation to salt leaching on soil profile[14].

RELEVANCE AND MAIN TARGETS

Currently local governments across Europe face an increasing problem with waste disposal due to the lack of controlled sewage disposal. The waste has often been deposited in non-controlled sewers thereby not only affecting the quality of life of the population in the vicinity of these sewers, but also leading to environmental degradation at the point of outlet. This is far from the objectives of the circular economy promoted by the European Union. This has, for example, severely affected the water quality and thus the ecology of the Mediterranean Sea. The possibility of recycling sewage sludge is a sound solution that the local governments could offer with the main aim of improving the quality of the environment and the lives of the affected population.

The re-utilization of wastes materials in rehabilitation of degraded land does not only provide a financially beneficial solution, but also contributes considerably to environmental protection. It addresses the aims of the Kyoto protocol by adding carbon to the soil system, which would otherwise be eventually oxidized and returned to the atmosphere. Finally, the interactions of our local companies with the European companies located in regions with similar problems are beneficial for the Sectors involved within these Communities.

The articles 174 to 176 of the consolidated version of the Treaty establishing the European Community concern the environment and one of the objectives is to promote measures at international level to deal with regional or world-wide environmental problems, which is clearly addressed in the scope of this proposal. The impetus to recycle post-consumer wastes is embodied within the European Commission Directive (94/62/EC), but how such material satisfies technical and market demands is unknown. New directives are expected to cover all aspects of industrial technology, including ethical and environmental issues. Equally, good industrial practices using as raw materials recycled by-products should be developed and implemented in every sector.

Wastewater sludge has long presented significant disposal challenges. Its composition, which includes nitrogen (N), phosphorus (P), and organic matter, renders it a valuable resource for fertilization and soil amendment. However, wastewater sludge may contain relatively high concentrations of certain heavy metals compared to levels found in unpolluted soils. These concentrations are often proportional to the degree of industrialization in the area served by the municipal WTP (Water Treatment Plants). When sewage sludge from WTP is applied to land, the soil's capacity to bind heavy metals and accumulate them in plant root zones raises critical questions about the impact of more soluble metals on biological life and soil activities. In European Union countries, where environmental awareness is growing alongside rapid industrialization, the number of wastewater treatment facilities has increased significantly, resulting in a substantial generation of sewage sludge as secondary waste. This rise in secondary waste has directed researchers toward investigating the challenges, characteristics, and potential applications of this material. The aim of this study was to assess the effects of applying sewage sludge to soil.

When sludge from WTP is applied to land, the soil's capacity to bind heavy metals and accumulate them in the root zones of plants raises critical concerns regarding the impact of more soluble metals on biological life and activities within the soil. In European Union countries, where environmental awareness is increasing alongside rapid industrialization, the number of wastewater treatment facilities has grown significantly, resulting in a substantial amount of sewage sludge as secondary waste. This increase in secondary waste has prompted researchers to investigate the issues, attributes, and potential utilization of this material. The objective of this study was to determine the effects of applying sewage sludge to soil.

Sewage sludges consist of multi-element organic wastes commonly utilized as fertilizers. The application of sludge to agricultural soils is regulated by various guidelines and regulations, typically focused on the concentrations of heavy metals within the sludge. However, the use of sludge on agricultural lands has raised significant concerns. It is frequently argued that heavy metals such as lead (Pb), nickel (Ni) and cadmium (Cd), present in sludge may enter the food chain through plants or animals, contaminate surface and groundwater, and pose health risks to humans and ecosystems.

In reality, metal concentrations in sewage sludge can vary significantly based on several factors, including (1) the origin of the sludge (e.g., industrial waste typically contains higher levels of heavy metals compared to residential waste) and (2) the pretreatment processes applied to the sludge (e.g., raw versus anaerobically treated). Additionally, the bioavailability of sludge-borne metals in soil is further influenced by soil properties such as pH, clay and sesquioxide content, and organic matter, as well as the rate of sludge application. This variability accounts for the observed lack of metal accumulation in plants cultivated in certain sludge-amended soils, as well as the beneficial effects of sludge on soil fertility and plant nutrition. Given this context, a comprehensive understanding of the fundamental chemistry of waste materials and their interactions with soil will enable sludge managers to make informed decisions regarding the application of sludge to agricultural lands.

CONCLUSIONS

The development of this research will contribute in a decisive way to preserve the environment in Europe. The demand for water treatment plants is continuously increasing, for this reason is timely to implement clear and viable solutions to this problem like those promoted in this project. Our research group has the aim to prepare reports covering the technical details, performance and applicability of the sewage sludge strategies with special consideration of the local and regional environmental conditions, legislation and practices. So, guidelines and recommendations will be derived and formulated in a final project meeting, involving also representatives from organizations named below, for the implementation of the water saving approaches under prevailing and foreseeable future regional, and trans-national conditions and constraints. In the other hand it is necessary active dissemination of project results addressing particularly decision- and policy-makers makers (incl. National Ministries for Water Resources/Irrigation) and key advisory organizations with strong dissemination activities to end-users (Water Demand Management Forum Middle East and North Africa, Land and Water Development Division of FAO, IPTRID Network, INPIN, IWRA), and the scientific community via papers in relevant international journals (preferably including a dedicated special issue) and conference contributions[29-31].

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