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Chapter 10

The Characteristics of Phytoremediation of Soil and Leachate Polluted by Landfills

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/61105

Abstract

Current landfill regulations provide for the responsible management of solid waste and a safer alternative to the outdated practices of open or illegal dumping. Aside from imparting aesthetic value, natural or planted vegetation on landfill sites has an important role in erosion control and removal of contaminants, and may also be used in leaching treatment. The use of leachate for the irrigation of landfill vegetation reduces its harmful effects, and the reuse of water aids in water conservation. The aim of this study was to search for ways to use leachate water from solid waste landfill sites for irrigation of plant species that normally grow in the wild. The study focuses on the plant species *Alcea rosea* (hollyhock), *Cynodon dactylon* (Bermuda grass) and *Melilotus officinalis* (yellow melilot). Over the 2-year study period, plants were irrigated with tap and leachate water under drought conditions. Wild plant diversity was identified, and the landfill was rehabilitated with various plant species. After the experiment, populations of *Escherichia coli*, total coliforms and fecal coliform bacteria in soil samples were analyzed. We observed that the use of leachate water for cultivation of different kinds of plants affected the density of total and fecal coliforms in the soil.

Keywords: Landfill, Leachate water, Remediation, Coliform bacteria

1. Introduction

With the rapid increase in population and urbanization, solid waste landfills are emerging as a major problematic urban infrastructure. Urban solid waste can be stored both underground and aboveground, but each creates environmental and human health risks.

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Those involved in solid waste management continue to search for ways to reduce these risks. Landfills are required to use synthetic and/or soil liners of site-specific thickness and hydraulic conductivity as well as various other safeguards to isolate the waste from nearby groundwater, air and soil [1].

Waste landfill management is an important concern, as negative effects are often caused by discontinuation of traditional management practices. The adverse effects on flora and fauna resulting from changes inland use patterns have been described by landscape ecologists throughout Europe [2], and have been reported by several authors for Mediterranean landscapes such as the montado and agro-silvopastoral systems in Portugal [3], the Tuscany region of Italy [4], the mountainous landscapes in northern Italy [5], and the shrub and woodland areas in Israel and other Mediterranean countries [6]. Aside from imparting aesthetic value, natural or planted vegetation on a landfill has an important role in erosion control and removal of contaminants, and may also be used in leaching treatment. Although phytoremediation of various contaminants has been investigated, the practical application of this technology to the remediation and rehabilitation of municipal solid waste landfill sites has not been sufficiently studied [7].

Areas of bare soil, where vegetation is not present, are open to erosion. The soil of landfills is not generally suitable for growing plants, and protective soil cover is needed. Additionally, planting will have no effect on erosion in the short term without the selection of optimal plants. In our previous study, we examined species best suited for this purpose and found that certain plants could be used for remediation of cover soil [7]. Other studies have found approximately 120 plant species, consisting of trees, shrubs, and grasses, that are appropriate for establishing plant cover in different types of vegetative amelioration [8, 9]. One of the most common plant mixtures used in rehabilitation is grasses and legumes. Grasses are regarded as most appropriate for protection from soil erosion, while legumes grow rapidly, particularly in soils with a low concentration of nitrogen [8, 10, 11].

Leachate is a major issue in landfills and surrounding areas, as it is very harmful to the environment. Leachate interacts with soil and ground and surface waters, and contains high degrees of organic and inorganic pollutants. It is the longest-lasting emission from landfills [12], and therefore the liquid waste causes considerable pollution [13]. One of the most promising methods for mitigating these effects is the use of leachate water for irrigation of vegetation planted on landfills. Research has shown that this technique enables the reuse of polluted water as a result of the remediating effects of plants and microorganisms. The landfill cover soil was irrigated with leachate for maintaining appropriate moisture content for methane oxidation reaction. Municipal solid waste compost was found to be an effective landfill cover material for controlling landfill gas emissions, exhibiting the highest methane oxidation rate [14]. Soil is a habitat for a great number of organisms, but at the same time, it is perhaps the most endangered component of our environment, and can be altered by the different pollutants arising from human activity [15, 16]. Prevention of soil pollution and its harmful effects, however, requires some basic knowledge of the soil characteristics. Soil has a very complex structure and exhibits greatly different properties among various regions [17].

http://dx.doi.org/10.5772/61105

Trace elements such as metals in contaminated soil also have negative impacts on human health and the environment, and thus their removal is often required. Metals can be stabilized by soil amendments to increase metal adsorption or alter their chemical form [18]. There have been few experiments comparing different in situ remediation treatments under similar environmental conditions or investigating whether all soil components or properties (e.g., microbes, soil fauna, plants, soil retention and colloid stability) are similarly protected. As part of the EU FP7 Greenland project (reference number 266124), we compared the impact of novel soil amendments and their combinations with traditional materials with regard to metal solubility and the response of plants, soil organisms and microbial activity [19]. Soil metal bioavailability is often cited as a limiting factor in phytoextraction (or phytomining). Bacterial metabolites such as organic acids, siderophores, and bio surfactants have been shown to mobilize metals, and the use of microbial inoculants to improve metal extraction has been proposed by several authors [20].

Plants, in combination with their associated micro flora, have a prominent role in remediating soils contaminated with organic pollutants such as petroleum hydrocarbons. Several plant-associated bacteria have the capacity to degrade hydrocarbons, promote plant growth and alleviate plant stress. In many cases, this is due to the fact that inoculant strains may not adequately interact with or colonize plants used for phytoremediation and/or cannot compete with the resident micro flora under certain environmental conditions. However, colonization and the competitive ability of inoculants trains is generally rarely addressed, despite the fact that an understanding of the efficiency of inoculation is essential [21].

In cases when phytoremediation is successfully performed, target pollutants play roles such as enhancing bioavailability by altering the flora or microbial community structure, either through stimulation of existing microbial degraders or through the introduction and establishment of new organisms [22]. For example, surface flow wetlands have proved to be successful in removing selenium (Se) from wastewater. Researchers also reported that constructed wetlands can remove up to 90 % of Se contained in the inflow of oil refinery waste water and up to 80 % from agricultural irrigation drainage [23].

As a result of manmade activities, large areas of soil are contaminated with multiple pollutants, and these high concentrations of pollutants have toxic effects on the environment. Plant microorganism-based technologies can supply a strategy for soil remediation and for the restoration of soil functionality after treatment [24].Soil conditions such as pH, the composition of organic matter and vegetation, and supplements influence soil micronutrient dynamics [25]. Soils may become polluted with high concentrations of heavy metals that are naturally produced by the melting of ore or artificially produced by industrial activities [26, 27].Among pollutants, heavy metals exceeding specific thresholds have been the subject of particular attention because of their long-standing toxicity. Their mobility in the ecosystem and transition through food chains are key issues in environment research [28–33]. Organic amendments may influence soil properties for years after application, as only a fraction of the organic material may be initially degraded or become available to plants and soil microorganisms [34, 35].

Issues with heavy metal contamination at landfill sites have recently been noted. Landfill remediation is generally performed by restoration of the site through the creation of a low

hill planted with plants indigenous to the area. The aim of the current study was to search for ways to use leachate water from solid waste landfill sites for irrigation of plant species that grow wild under normal climate conditions. The study focuses on the plant species *Alcea rosea* (hollyhock), *Cynodon dactylon* (Bermuda grass) and *Melilotus officinalis* (yellow melilot). During the 2 years of the study, plants were irrigated with tap and leachate water under drought conditions. The wild plant species were determined in the hollyhock, Bermuda grass and yellow melilot parcels. After the experiment, populations of *E. coli*, total coliforms and fecal coliform bacteria in the soil samples were analyzed. Results showed that using leachate water to cultivate various types of plants affected total and fecal coliform populations in the soil.

2. Characteristics of the Adana-Sofulu landfill and the plants used for remediation

The Adana-Sofulu landfill is the first major landfill in Turkey at which scientifical planting rehabilitation has been conducted. The population of Adanais 2,026,319, and Adana Province is the political and economic center of the Cukurova region. Field experiments were conducted between 37°03′12″N and 37°03′12.1″N and between35°23′34.3″E and 35°23′35″E [8] (Figure 1).

The city of Adana is in the Mediterranean climate region, and during this study,plants were irrigated with leachate water and tap water during the drought season. Figure 2 shows temperatures and rainfall amounts, including the drought season, for the city of Adana [36]. The irrigation was conducted from May to September.

Until recently, there has been no urgent need for planting of landfill areas. Landfills were generally transformed into small copses within 20 years after the planting of populous species that would grow to a depth of 30 cm from the soil surface. In later years, however, toxic degradation products of waste compounds have created issues that have brought about the need for new planting strategies [37].

Typical plant remediation methods in landfill areas include “grassing” and “grassing and reforestation”. In the grassing method, 20-cm class I and II soil layers are laid on wasteland, and a mixture of *Lolium*, *Dactylis*, *Poa, Agrostis*, *Cynodon*, *Trifolium*, *Medicago* and *Vicia* seeds are planted there. This method of rehabilitation of landfill areas is very common in England. In grassing landfill areas, trees are just an ornamental element. With the grassing and reforestation method, it is important to determine the timing of landfill closures. With old landfill sites, there are no serious problems with the timing of planting. Soil that has been incubated in a fermentation process is laid on the waste site at a thickness of 30 cm, and grassing then begins with the seeding of *Lolium*, *Dactylis*, *Trifolium* and *Poa.* In this process, the grassy vegetation is first laid on the soil layer. After the vegetation has been established, the *Populus* and *Salix* species are planted to begin reforestation [38, 39].

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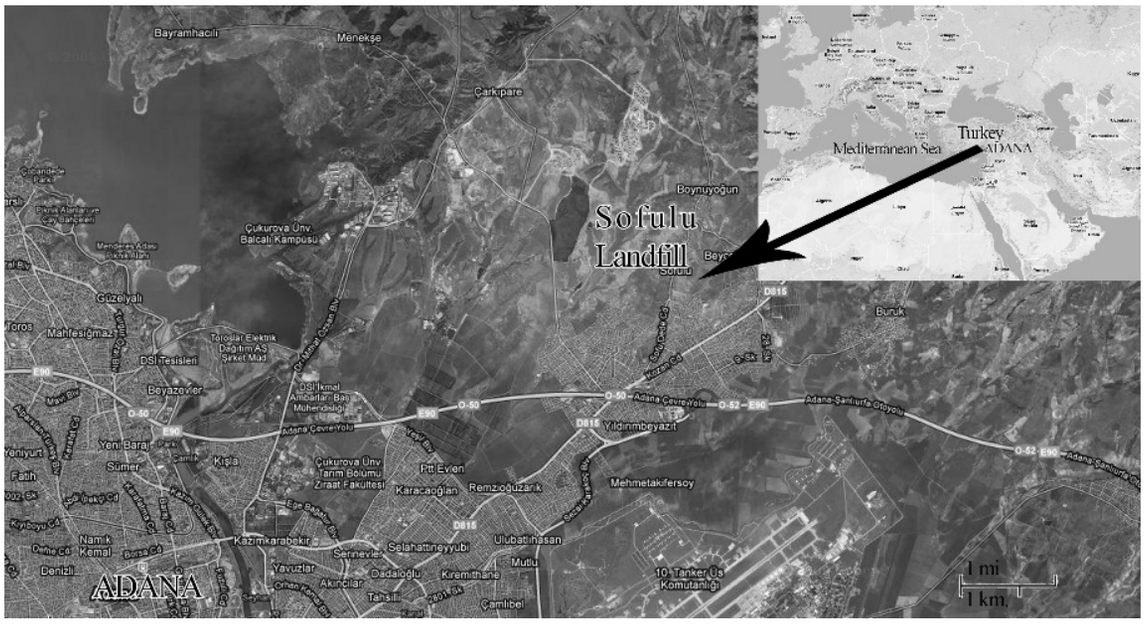


Figure 1. Map showing location of the Sofulu landfill [8]

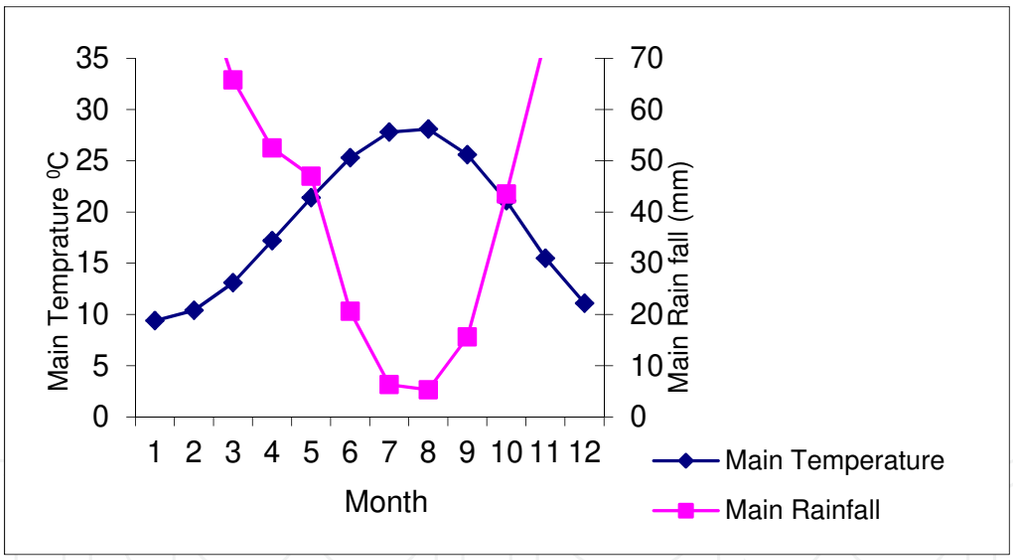


Figure 2. Drought index of study area [36]

In the Sofulu landfill rehabilitation study, three plant species—*Alcea rosea* (hollyhock), *Cynodon dactylon* (Bermuda grass) and *Melilotus officinalis* (yellow melilot)—were selected on the basis of their ecological characteristics including area of spread, the need for soil nutrient sand their tolerance to extreme temperatures. These plants require few nutrients. Each plant species has a different seed weight. To obtain equal numbers of seeds, we followed the recommended weights for plants. Accordingly, 80 g of *A. rosea*, 600 g of *C. dactylon* and 3 g of *M. officinalis* seeds were sown on each parcel. Figure 3 shows photographs of the three plant species [8].



A. rosea flower (hollyhock) (Original)



A.rosea plant group in the plot (Original)



M. officinalis flower (yellow melilot)(Original)



M. officinalis plant group in the plot (Original)



C. dactylon (Bermuda grass) (Original)



C. dactylon covering in the plot (Original)

Figure 3. Photographs of plant species in the plots

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3. Change in vegetation at the planted plots

The experimental design of the study was based on the plot applications, and the study was conducted at three independent plots. Treatment equipment was constructed in the Sofulu waste landfill, which was covered with 30 cm of soil in the B soil horizon. Experimental plots 6 m^2 (2 m × 3 m) in size were prepared, and three types of plants (*A. rose, C. dactylon* and *M. officinalis*) were each planted on 6 plots. The climate in the site is typical of the Mediterranean, and is characterized by a hot, dry period between May and September. The mean annual rainfall in the area is 647 mm, which occurs in the winter and spring seasons, and therefore irrigation is necessary in the summer for any plant growth [8].

The plants in the experiments were irrigated with either tap water or leachate wastewater under drought conditions. Nine plots were not irrigated and were used as controls in order to evaluate the effects of irrigation. The leachate waste water was taken from the basin of the Sofulu landfill site [8]. Figure 4 shows the changes in vegetation at the plots of south waste landfill over 2 years. Few plants were observed in the spring after plant seeds were sown in February. However, growth of *A. rosea* was observed, and the flower bloomed in autumn of that year; *M. officinalis* and *C. dactylon* also grew in the spring of the following year. Moreover, the mixed vegetation of the three plants was found in the next autumn. Subsequently, 41wild plant species were also seen in the experiment parcels. The names of the species are given in Table 1. In this study, gramines (*Bromus arvensis, Lolium temulentum* and *Polypogon monspeliensis)* grew in high numbers in the plot irrigated with tap and leachate wastewater.

Figure 5 shows high numbers of *L. temulentum* and *Silybum marianum* in the plots. In contrast, legumes (*Lathyrus annuus, Psoralea bituminosa, Trifolium campestre* and *Trifolium speciosum*) were not able to propagate insufficient numbers. A study by Arambatsiz et al. [11] was able to achieve significant rehabilitation after mining activities with gramines and legumes, and another study[40] reported that gramines and legumes were grown for the rehabilitation of a degraded study area.

We were able to obtain a sufficient number of wild plants on the landfill and achieve a green landscape when the field was irrigated with leachate water during the drought season. Therefore, the planting of appropriate plants and the use of irrigation by leachate water appears to be an efficient means of rapid landfill remediation as well as removal of pollutants contained in leachate water.

As shown in Table 1, the highest number of wild plant species, 21, was in the *M. officinalis* plots. The *C. dactylon* plots had 17 and *A. rosea* plots had 16 wild plant species with landfill leachate irrigation. *C. dactylon* is so dominant plant species [41, 42], Figure 6 shows that it did not permit to sprawl the wild plants in some plots. *M. officinalis* was also dominant in the spring in some plots.



The first spring in the study area



The second spring in the study area



The first autumn in the study area



The second autumn in the study area

Figure 4. Change in vegetation at the plots of the Sofulu landfill



Lolium temulentum in the plot



Silybum marianum in the plot

Figure 5. High-number species in the plots

http://dx.doi.org/10.5772/61105



C. dactylon plot



M. officinalis plot

Figure 6. Some of the dominant species in the plots

Wild species	**Waste leachate irrigation**			**Tap water irrigation**		
A.rosea	*C. dactylon*	*M. officinalis*	*A.rosea*	*C. dactylon*	*M. officinalis*	
Ainsworthia trachycarpa		*r*			*r*	
Anagallis arvensis				*r*		
Avena sterilis					*r*	*r*
Alcea rosea		*r*				
Bromus arvensis	*r*					
Capsella bursa-pastoris	*r*			*r*		
Carthamus lanatus		*r*	*r*			
Carthamus dentatus			*r*			
Catapodium rigidum				*r*		
Chenopodium album	***r***			*r*		
Conyza canadensis			*r*			
Carduus pycnocephalus			*r*	*r*	*r*	*r*
Crepis sp.	*r*			*r*		
Cynodon dactylon	*r*		*r*	*r*		*r*
Echinops ritro					*r*	
Helminthothecaechioides		*r*	*r*	*r*		*r*
Hordeum marinum	*r*	*r*	*r*		*r*	*r*
Lathyrus annuus			*r*			

Wild species	Waste leachate irrigation			Tap water irrigation		
Lactuca serriola	*r*	*r*	*r*		*r*	*r*
Lolium temulentum	*r*	*r*	*cd*	*cd*	*cd*	*r*
Melilotus officinalis	*cd*	*r*		*r*	*r*	
Polygonum aviculare		*r*	*r*			*r*
Polygonum equisetiforme						*r*
Polygonum lapathifolium		*r*	*r*			
Polypogon monspeliensis	*r*		*r*	*r*	*r*	*cd*
Psoralea bituminosa					*r*	
Psoralea bituminosa		*r*				
Rumex acetosa		*r*				
Scrophularia canina				*r*		
Senecio vernalis				*r*		
Setaria viridis	*r*	*r*	*r*	*r*	*r*	*r*
Silene colorata	*r*		*r*	*r*		
Silybum marianum		*r*	*cd*	*r*	*r*	
Sinapis arvensis	*r*	*r*	*r*	*r*	*r*	*r*
Sonchus oleraceus		*r*	*r*	*r*	*r*	*r*
Stellaria media					*r*	
Trifolium campestre	*r*		*r*			
Trifolium lappaceum				*r*		
Trifolium speciosum	*r*					
Triticum aestivum L.	*r*					
Verbena sp.				*r*		

cd co-dominant presence (50–80 %), *r* rare presence (1–20 %), *blank columns* no presence

Table 1. Wild plant species grown in plots irrigated with leachate wastewater and tap water [8, 36]

The dominance of plants belonging to four families, viz., Poaceae, Asteraceae, Polygonaceae and Chenopodiaceae, while other species were found to occur only sporadically in the Stockholm, Malmo and Helsingborg landfills of Sweden [43].At the Kodungaiyur and Perungudi dumping grounds in Chennai, India, the dominant plant species recorded were *Acalypha indica*, *Solanum lycopersicum, Parthenium hysterophorus*, *C. dactylon* and *Cucurbita maxima* [44].

The wild plant species in the Sofulu landfill experimental plots are shown in Figure 7.

http://dx.doi.org/10.5772/61105



Figure 7. The wild plants in the Sofulu landfill experimental plots

4. Microbial soil analysis

Over the2-yearstudy period, plants were irrigated with tap water and landfill leachate water during drought conditions (May to September). The landfill leachate water was taken from the collection basin of the Adana Sofulu landfill site. Tables 2 and 3 show the physiochemical, biological and microbial characteristics of landfill leachate water used for the irrigation.

There are three groups of coliform bacteria. Each is an indicator of water and soil quality, and each has a different level of risk. Total coliforms are a large collection of different kinds of bacteria. Fecal coliforms are types of total coliforms that exist in feces, and *Escherichia coli* is a subgroup of fecal coliforms. Total coliform bacteria are common in the environment (soil or vegetation) and are generally harmless [45].

Landfill leachate water showed high concentrations of nitrogen, phosphate and minerals at pH values of 7.9–8.4, and therefore, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were high, suggesting that landfill irrigation with leachate water may enhance microbial concentration. Microbial density at the plots was thus examined, and these characteristics were analyzed according to standard methods[46].

Parameters	July 1st year	August 1st year	May 2nd year	June 2nd year	July 2nd year	August 2nd year
COD (mg/l)	960	3750	4315	3100	3585	4060
BOD(mg/l)	552	1950	52	47	50	41
pH	8.2	7.9	8.0	8.3	8.1	8.44
NO_2-N (mg/l)	-	-	1.6	2.54	0.40	0.37
PO_4-P (mg/l)	-	-	2.832	7.560	4.880	5.284
Zn (mg/l)	0.2	0.4	0.06	0.04	0.02	0.07
Fe (mg/l)	0.8	1.4	3.5	2.6	0.868	15.2

COD chemical oxygen demand, *BOD* biochemical oxygen demand

Table 2. Landfill leachate water properties [8, 36]

Soil samples were collected from three locations within each treatment parcel and mixed. The soil was used for analysis of fecal total coliforms and fecal coliform bacteria. Each soil sample was mixed with sterile water or physiological saline and divided into three subsamples. A membrane filter technique was used for all bacteriological assays [47]. Microorganisms containing thermo tolerant fecal coliforms transferred onto the membrane were incubated on fecal coliform (M-FC, Difco Laboratories, Inc.) agar medium for 24 h at 44.5 °C, and the number of colonies was counted. In the case of *E.coli*, the cells transferred onto the membrane were incubated in M-FC agar medium containing 4-methylumbelliferyl-β-D-glucuronide for 4 h at

Parameter	July 1st year	August 1st year	May 2nd year	June 2nd year	July 2nd year	August 2nd year	Limit value
Total coliform bacterial count (CFU/100ml)	7×10^3	7.1×10^2	3.2×10^6	2×10^7	-	-	-
Fecal coliform bacterial count (MPN/100ml)	>1100	>1100	>1100	>1100	>1100	>1100	1000
*E. coli*count (MPN/100ml)	>1100	>1100	>1100	>1100	>1100	>1100	1000

CFU colony-forming units, *MPN* most probable number

Table 3. Landfill leachate water microbial properties [8, 36]

35 °C. The colonies generating blue fluorescence by exposure to a longwave UV light (366 nm) were counted as *E. coli* cells. The minimum indication level was approximately 30colony-forming units (CFU)/ml, whereas the maximum cutoff level was 300 CFU/ml.

The mean values were compared between groups using one-way ANOVA. A significance level of $P<0.05$ was used throughout the study. The SPSS Version 10.0 software program [48] was used for these statistical analyses. Duncan's multiple range test was applied to bacterial count data.

5. Effect of landfill and leachate water on microorganisms

Soil is generally a favorable habitat for the proliferation of microorganisms, with micro-colonies developing around soil particles [49]. Bacteria comprise the most abundant group of microorganisms in the soil ($3.0\times 10^6$to 5.0×10^8 per gram of soil), followed by the actinomycetes ($1.0\times 10^6$to 2.0×10^7), fungi ($5.0\times 10^3$to 9.0×10^6), yeast ($1.0\times 10^3$to 1.0×10^6), algae and protozoa ($1.0\times 10^3$to 5.0×10^5), and nematodes (50–200 per gram of soil),with wide differences in the relative proportions of individual bacteria genera found in particular soils[50, 51]. In this study, the total coliform bacteria count varied from $2.1\times10^5$to 7.4×10^5 in landfill soil.

The number of extant bacterial species is thought to range from 3×10^4 to 3×10^6[52], of which only a small fraction have been cultured and identified [53,54]. Mayr et al. reported that due to differences in cultivability among soils, the number of cultivable bacteria per ml inoculums ranged from 0.6×10^3 (forest soil) to 7×10^3 (agricultural soil),with significant variability [55]. *E. coli* and thermo tolerant coliform bacteria are widely used as indicators of soil characteristics. However, many microorganisms, including ente rococci, coliphages, and sulfite-reducing clostridial spores, have been suggested as microbial indicators of fecal pollution [56], and anaerobic digestion processes, if operated properly, have long been known to successfully

reduce the number of pathogens and indicator organisms [57,58]. In a study by Zhang et al. investigating microorganism concentration in raw sewage, the bacterial indicators total and fecal coliforms were enumerated. The average concentrations of total and fecal coliforms were 2.5 $\times 10^7$ CFU/100 ml and 9.6$\times 10^6$ CFU/100 ml, respectively [59].

In the last a few years, researchers have reported higher fecal coliform populations, on a dry solids basis, in centrifugally dewatered bio solids compared to digester effluents [60–67]. Therefore, landfill irrigation by leachate water may represent a key process for landfill remediation and rehabilitation.

Tables 4 and 5 show the microbial density at the plots. As shown in Table 4, the density of fecal and total coliforms increased with the use of leachate water, with almost equal amounts between landfill and clean areas, which suggests that leachate water irrigation is an effective method of landfill remediation. The effects of the plants were also examined, as shown in Table 5. The types of plants affected the amount of fecal coliforms, with the highest concentration in the area planted with *A. rosea* (8.6 $\times 10^3$).

	Fecal coliform bacteria (Count per gram)	**Total coliforms (CFU per gram)**
Factors		
Clean area + tap water	3.2 $\times 10^2$ *a*	2.1$\times 10^5$ *a*
Clean area + leachate water	1.0$\times 10^3$ *b*	7.4$\times 10^5$ *b*
Landfill + leachate water	1.0$\times 10^3$ *b*	5.0$\times 10^5$ *ab*

Data analyzed using Duncan's multiple range test. *b* maximum value, *ab* intermediate value, *a* minimum value. Alpha = 0.05

Table 4. Changes in fecal coliform bacteria and total coliform density in soil for different factors

Plots	**Fecal coliform bacteria (count per gram)**
M. officinalis	6.0$\times 10^2$ *a*
A. rosea	8.6$\times 10^3$ *b*
C. dactylon	1.0$\times 10^3$ *ab*

Data analyzed using Duncan's multiple range test. *b* maximum value; *ab* intermediate value, *a* minimum value. Alpha = 0.05

Table 5. Changes in fecal coliform bacterial density in the soil with different plant species

http://dx.doi.org/10.5772/61105

6. Conclusions

Solid waste landfill sites pose a significant hazard to natural life, and mitigation of these harmful effects has posed a major challenge. This study proved that the use of leachate wastewater for plant breeding on a landfill in drought weather conditions caused a change in microbial activity in the landfill cover soil. If leachate is used for irrigation, the site should be safely enclosed by fencing, given the negative microbial effect on human health.

Landfill rehabilitation has a positive effect on the landscape. In today's world, waste reduction is critically important, as is the need to ensure that people are able to live in a healthy and beautiful environment. The transformation of brownfield areas into healthy green landscapes using recycled wastewater is an area of research that should be a primary focus of scientists.

This paper examines reasons for considering the use of plant remediation for microbial pollution in landfills. These areas offer the potential for improving biodiversity, and turning these problem areas into opportunities requires the selection of the appropriate plants and the most effective technique. The re-vegetation of landfills can increase biodiversity as well as reduce microbial pollution. This article provides an example of such a strategy for landfills in the Mediterranean climate zone.

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