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Applicability of leachates originating from solid-waste landfills for irrigation in landfill restoration projects

Reyhan Erdogan[1], Zeynep Zaimoglu[2], M. Yavuz Sucu*[2], Fuat Budak[2] and Secil Kekec[2]

[1]Department of Landscape Architecture, University of Cukurova, Balcali Kampusu - 01330, Yuregir, Adana, Turkey

[2]Department of Environmental Engineering, University of Cukurova, Balcali Kampusu - 01330, Yuregir, Adana, Turkey

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Abstract: *Since, landfill areas are still the most widely used solid waste disposal method across the world, leachate generated from landfills should be given importance. Leachate of landfills exerts environmental risks mostly on surface and groundwater, with its high pollutant content, which may cause unbearable water quality. This leads to the obligation for decontamination and remediation program to be taken into progress for the landfill area. Among a number of alternatives to cope with leachate, one is to employ the technology of phytoremediation. The main objective of this study was to determine the N accumulation ratios and the effects of landfill leachate in diluted proportions of chosen ratios (as 1/1, 1/2, 1/4, 0), on the growth and development of Cynodon dactylon, Stenotaphrum secundatum, Paspalum notatum, Pennisetum clandestinum, Mentha piperita, Rosmarinus officinalis, Nerium oleander, Pelargonium peltatum and Kochia scoparia species. In order to simulate the actual conditions of the landfill, soil covering the landfill is taken and used as medium for the trials. The study showed that S. secundatum, K. scoparia and N. oleander species had an impressive survival rate of 100%, being irrigated with pure leachate, while the others' survival rates were between 0 to 35% under the same conditions. As expected, application of leachate to the plants caused an increase in the accumulation of N, in the upper parts of all plants except P. peltatum. The highest N content incresase was observed at S. Secundatum set, accumulating 3.70 times higher than its control set, whereas P. clandestinum value was 3.41 times of its control set.*

Key words: *Landfill leachate, Pollution control, Natural treatment systems, Landfill restoration*
PDF of full length paper is available with author ***(*ysucu@cu.edu.tr)***

Introduction

Clean, fresh water is one of the Earth's natural diminishing resources and its utilization now requires a much more perfected management. Especially in dry regions, along with the search for potentials of water reuse, minimizing the use of clean water in irrigation should be incorporated in water management, which also should cover preservation of fresh water bodies from being lost by interaction with pollution sources, like solid waste landfill systems (Sogut *et al.*, 2005; Archana *et al.*, 2005; TCSV, 1989; Hooda, 2007). Solid waste dump sites require improvement, rehabilitation, maintenance and management during and after operation, and also leachate generated should be handled by a sound and economical method. Several methods have been employed for removal of organic and inorganic pollutants and to improve the leachate quality besides being as precaution to prevent pollutant transport by means of leachate and groundwater interaction (Bech *et al.*, 2002; Sogut *et al.*, 2005; Indra and Sivaji, 2006). In the US, EPA (Environmental Protection Agency) has adopted two approaches in "liquid management strategy" related to leachate. (1) To minimize the formation of leachate by keeping liquids away from the source and garbage area, (2) To expose, collect and discharge the leachate (EPA, 2000). For most cases that a landfill is in operation, second approach is the only way to prevent water resources from leachate interference.

In Australia, China and Thailand, plants have been employed in order to improve the quality of leachate (Truong and Hart, 2001). In Turkey, studies aiming to decrease leachate quantity and improve its quality seem to be insufficient. In order to prevent leachate being infiltrated or washed off, a recirculation pond was constructed, in which leachate had been collected from the Adana-Sofulu waste dump site. But the spread of leachate was not completely prevented. Truong and Hart (2001) reported that there are two ways to increase the quality of polluted waters. One is to control pollution factors before intrusion to the water; the other is removing the pollution factors from the water. Phytoremedition, which is accepted as an alternative method to increase the environmental quality of air, water and soil, briefly is inactivation of the pollution factors harmful to the environment by using various methods (Cunningham and Berti, 1993; Cunningham *et al.,* 1995; Henry, 2000). Numerous woody and grassy plant species were reported to be capable of cleaning up the leachate. These plants can continue their growth and development in spite of organic and inorganic pollution conditions of water and other stress generating characteristics (low pH, negative COD, and BOD values), furthermore, plants help to improve the quality of the water (Zaimoglu, 2006). These species also increased the quality of land where planted, with synthesis of biomass. It is reported that vetiver grass (*Vetiveria zizanioides* L.) has successfully been used for improving the quality of leachate. In Troung and Hart (2001) studies conducted in China, irrigating vetiver grass for 66 days with leachate, the amount of N in the leachate decreased from 1125 mgl^{-1} to 232.2 mgl^{-1} and from 293.8 mgl^{-1} to 84.8 mgl^{-1} for two different leachate of strength. With the measurements on pod soil it was determined that the total nitrogen was decreased 79.4% and 71.1% for high and low concentration leachate irrigations respectively. Metal resistant ecotypes among grasses have been used for restoration of polluted lands (Cooke and Johnson, 2002). *Cyndon dactylon* was observed

Table - 1: Characteristics of the leachate

Parameter	Mean value	Parameter	Mean value
Chemical oxygen demand (mgl^{-1})	2355	PO_4-P (ppm)	10.36
Biochemical oxygen demand (mgl^{-1})	1253	Chrome (ppm)	1.50
AKM (mgl^{-1})	310	Copper (ppm)	0.23
pH	7.77	Lead (ppm)	0.46
NH_3-N (ppm)	16.03	Zinc (ppm)	0.30
NO_2-N (ppm)	2.13	Iron (ppm)	1.10

to give successful results in a wetland polluted with Pb, Cu, Zn, Cd, Tl, Sb and As (Del Rio *et al*., 2002). Combination of *Cynodon nlemfuensis* (star grass) and *Pennisetum clandestinum* Chiov (Kikuyu grass) remained alive and showed favourable growth values severely stressive conditions in the study conducted in a district of Zimbabwe which had been affected by municipal wastewater for 29 years (Madyiwa *et al*., 2002). Aksoy and Ozturk (1997) determined *Nerium oleander* as a useful biomonitor which can be used in polluted waters. It is observed that in a study conducted by using *Cynodon dactylon* in the Sofulu area that this species covered 53.5% and 98% of the space in the first and second year respectively and formed healthy, dark green foliage and more succulent tissue in comparison with the control plants.

The purpose of this study was to investigate the possibility of using some plant species that can be grown under the condition of irrigation with leachate and contribution to uptake nitrogen from leachate of solid waste dump sites, during the dry period of Mediterranean climate in Turkey.

Materials and Methods

This experimental study was conducted in the Adana city region in the Eastern Mediterranean region which has all the typical characteristics of that climate. The area receives a mean of 650 mm/ year precipitation and a mean temperature of 18.8°C. The experiment was driven outdoors and the application of leachate was given to the plants during the dry season of Adana between April and October.

The seeds *Pennisetum clandestinum, Paspalum notatum* were sown in small pots (7.5 cm x 7.5 cm) in April and transplanted to 2 l-pots in May. Other species were planted in 2 l-pots in April. Application of leachate to the plants started in July 2002, when the local climate turns into the dry season. It should be noted that the pots were lined with PVC sleeves, in order to prevent any outflow.

Landfill leachate was taken from the collection basin of the Adana Sofulu landfill site. Table 1 presents some of the physiochemical and biological characteristics of the leachate used. These characteristics were analyzed according to the standard methods (APHA, 2005). In order to prevent from microorganism activities, the leachate samples were frozen at -2°C and stored for use.

The reactions to leachate of 9 plant species (*Cynodon dactylon, Pennisetum clandestinum, Paspalum notatum, Stenotaphrum secundatum, Kochia scoparia Mentha piperita, Rosmarinus officinalis* and *Nerium oleander)* were tested by

Table - 2: Characteristics of the soil

Parameter	
pH	7,68
Structure	Clay-loam (CL)
Sorption capacity (cmol(+) kg^{-1})	1,69
Field capacity (%)	31
Organic content (%)	0,9
PW (%)	20
Salinity (dS m^{-1})	0.04
Iron (ppm)	5,2
Zinc (ppm)	0,6
Copper (ppm)	0,4
Magnesium (ppm)	2,6

irrigating with leachate in three different dilutions as pure leachate (PLW), 1/2 leachate (1/2 LW), 1/4 leachate (1/4 LW) and distilled water (CW). Also a control group was set for each dilution and replication. Leachate was diluted with distilled water, where irrigation of control groups done with distilled water as well. Each pot was watered 26 times during the experimental period with a total of 8250 ml water.

Soil, collected at a depth of 0-10 cm and 0-30 cm from the landfill site so as to simulate real life conditions, was passed through a 2 mm sieve and homogenized with a gardening mixer and used as medium for the plants. Physical and chemical properties of soils, such as texture and pH, were determined according to the methods described by Ostrowska (Ostrowska *et al.*, 1991). Heavy metal analysis of the soil samples was done according to Jones *et al.* (1991). This method includes the soil samples to be sieved and dried at 60°C for five days. A soil sample (2 g) was digested in 12.5 ml of HNO_3 (4 M) for 12 hr at 80°C, after cooling to room temperature, the digest was brought to 25 ml with deionized distilled water. The aqueous solutions were filtered through Whatman filter paper no. 42. Samples were serially diluted. Types and amounts of heavy metals in the soil were analyzed for heavy metal concentration using spectrophotometer (Nanocolor 100D) and its respective metal analysis kits. Table 2 presents the characteristics of the soil used.

Nine plant species were tested in the experiment. Four of them are grass species which belong to the family of Poaceae have adapted to a wide range of soils and have good drought tolerance and they are reported to be good for erosion control (Skerman and Riveros, 1990). These are *Cynodon dactylon* (bermuda grass), *Pennisetum clandestinum* (kikuyu) *Paspalum notatum* (bahia grass) and *Stenotaphrum secundatum* (buffalo grass).

Table - 3: Plant growth results of applications

	Leachate conc.	Root	Upper parts	Color	Survival rate (%)
Cynodon dactylon	CW	9	9	Light yellow	100
	PLW	9	9	Dark green	1
	1/2 LW	9	9	Dark green	40
	1/4 LW	9	9	Dark green	80
Pennisetum clandestinum	CW	9	7	Light green	100
	PLW	9	9	Dark green	25
	1/2 LW	9	9	Dark green	50
	1/4 LW	9	9	Dark green	60
Paspalum notatum	CW	9	7	Light green	100
	PLW	7	7	Dark green	1
	1/2 LW	9	9	Dark green	40
	1/4 LW	9	9	Dark green	80
Stenotaphrum secundatum	CW	9	9	Yellow-green	100
	PLW	9	9	Dark green	100
	1/2 LW	9	7	Dark green	100
	1/4 LW	9	7	Dark green	100
Kochia scoparia	CW	7	5	Yellow-green	20
	PLW	7	5	Green	100
	1/2 LW	7	5	Green	55
	1/4 LW	7	5	Dark green	65
Nerium oleander	CW	7	5	Light green-yellow	100
	PLW	7	5	Dark green-spotted	100
	1/2 LW	7	5	Dark green-spotted	100
	1/4 LW	7	5	Dark green	100
Pelargonium peltatum	CW	3	3	Green	100
	PLW	3	1	Light green	5
	1/2 LW	5	3	Green	50
	1/4 LW	5	3	Light green	70
Mentha piperita	CW	7	1	Green	100
	PLW	7	-	-	0
	1/2 LW	7	-	-	0
	1/4 LW	7	-	-	0
Rosmarinus officinalis	CW	3	1	Yellow-green	100
	PLW	3	1	Green	35
	1/2 LW	3	5	Green	65
	1/4 LW	3	5	Dark green	100

During the experiment live plant rate and growth characteristics were observed. Visual assessment for plants of root and upper part were done according to Kolb visual assessment techniques (Kolb, 1981). The assessment scales were described as 1: Impression insufficient, 3: Impression sufficient, 5: Impression satisfying, 7: Impression good and 9: Impression very good (Table 3).

At the end of the experiment, harvesting was completed on 10 March. Plants were cleaned and separated as under (roots) and above ground (shoot and leaves) parts. The plant material was dried at 300ºC for 2 hr, and powdered to be analyzed. The Nitrogen concentrations in the powdered plants were analyzed according to the Kjeldahl methods (Bremmer, 1965). In addition to the plant analysis, remaining N concentrations in the soil were analyzed, as no outflow (excluding ET) had occurred.

Results and Discussion

Application of landfill leachate on plants expanded the survival rate of the plants, except *Stenotaphrum secundatum, Mentha piperita, Nerium oleander*, which succeeded to perform at a survival rate of 100% in all applications, decreased visibly. Especially *Cynodon dactylon, Paspalum notatum* and *Pelargonium peltatum* species showed a dramatic decrease in the survival rate to about 5% with the increased concentration of leachate in irrigation water. Among these, the most striking result was obtained from the species of *C. dactylon*. At the application of this kind of pure leakage water, it displayed only 1% survival rate at the end of the trial. In the trial, conducted in the Sofulu solid waste landfill area, in the condition of irrigation with pure leakage water, *C. dactylon* covered 98% of the land in a period of two years. This is important evidence that grass

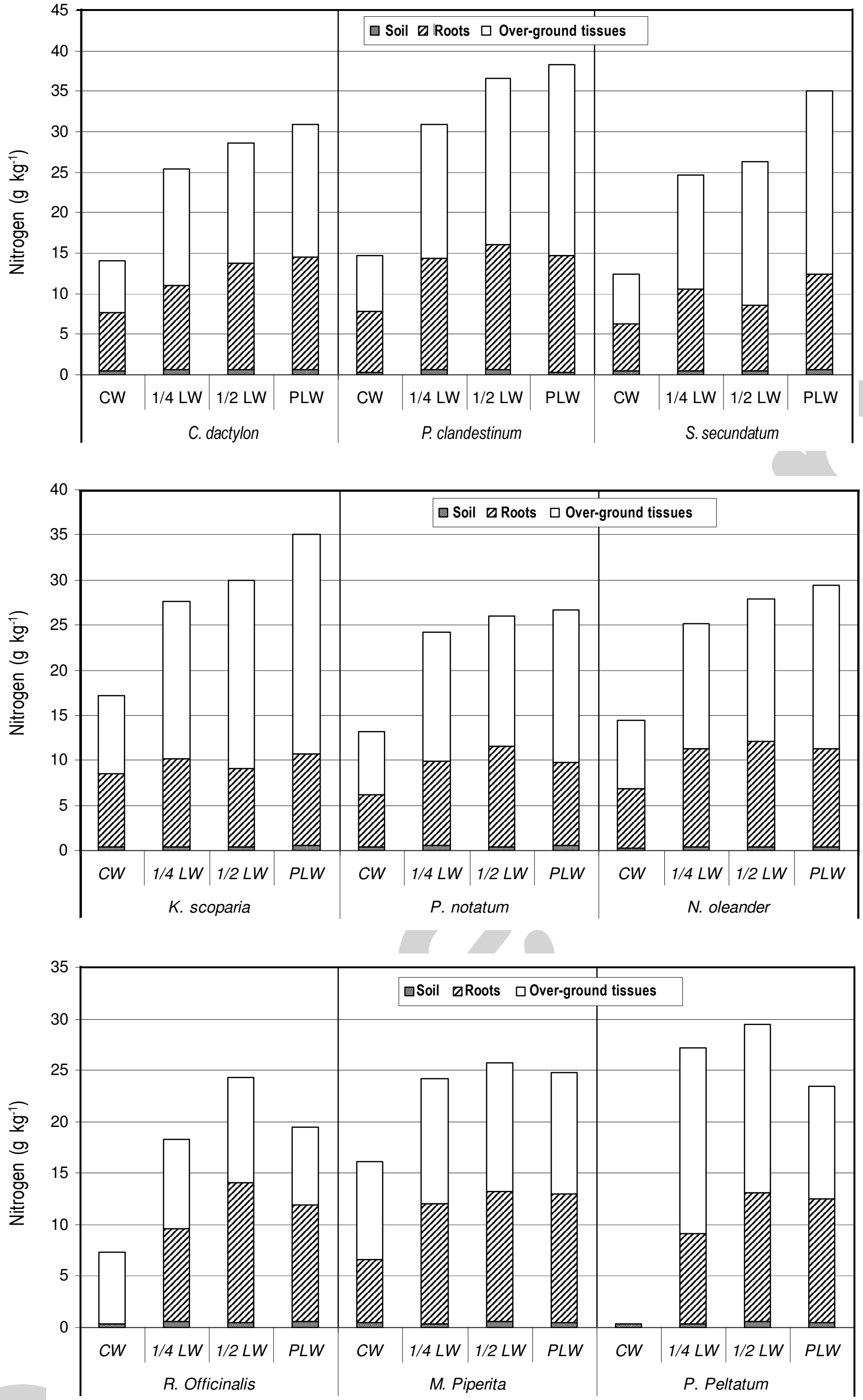

Fig. 1: Nitrogen contents of soil, root and over-ground tissues of (a) *C. dactylon*, *P. clandestinum*, *S. secundatum*, (b) *K. scoparia*, *P. notatum*, *N. oleander* and (c) *R. officinalis*, *M. piperita* and *P. peltatum* are given in mg kg^{-1}

species used in the trials can display higher survival rates under field conditions. Generally, with the increasing percentages of N (excessive nitrogen), plants grow and exhibit a dark green color and a more succulent cell structure (Ozbek *et al.*, 1984). Likewise, all grass species irrigated with leakage water displayed coarser cell structure and darker green color compared to the control plants under this condition, the amount of nitrogen in the leakage water played an important role. Also these plants developed a much taller height than the control plants. Generally while the remaining height of the control plants of all the species was about 10 cm, these plants reached up to 30-40 cm. The best result was obtained from *Stenotaphrum secundatum*. It reached a height of up to 30 cm and formed more and longer of stolen compared to control plants. All grass species covered the pod surface completely. Cossu *et al*. (2001), reported that *Stenotaphrum secundatum* has a better survival rate and lower sensitivity to leakage water when grown on platforms in leakage water. Grass species used at the trial were the plants used for some phytoremediation activities (Privetz, 2001; Cossu *et al*., 2001). For this reason, it is thought that the positive reaction of species for different contaminations was revealed at the applications of his trial.

Among all these species, the worst results were obtained from *Mentha piperita*. Leachate applications, in comparison to the control group, caused the display of darker green color in all species except *Pelargonium peltatum* species. While the color of the individuals of *Nerium olander* species irrigated with clear water were light green and yellow, brown specks were seen on the leaves which were irrigated with pure or 1/2 diluted leakage water. Although other species showed a decrease of survival rate with increasing leachate concentration, these decreases were not of magnitudes that affected the outcome of this study.

As it was expected, all species were observed to embody higher concentrations of N than control sets by application of landfill leachate. Moreover, plants that were irrigated with increasing concentrations of leachate accumulated higher amounts of nitrogen. The nitrogen content of plants (given in 2 parts to roots and upper bodies) and the nitrogen that remained in the soil are given in Fig. 1, implying plants uptake from the soil and accumulate the nitrogen.

As it can be seen in Fig. 1, for all mediations the nitrogen content in the soil remained nearly constant, which implies N was mostly uptaken and accumulated by the plants. *C. dactylon, P. clandestinum, S. secundatum* in Fig. 1(a) and *K. scoparia* in Fig. 1(b) seem to uptake high amounts of N, however this does not mean these species are resistant to leachate, due to the low survival rate of *C. dactylon*. Total nitrogen accumulation in the bodies of these plants show a sharp increase in the concentration of leachate and, nitrogen at the same time as the irrigation water is increased, showing the ability to uptake and accumulate N. In the applications of pure leachate, the amounts of nitrogen accumulation in the upper parts of *P. clandestinum* and *S. secundatum* are higher than that of the other two species. All of the leakage water applications caused more nitrogen accumulation in the upper parts of *P. clandestinum* than in the other grass species. It was reported by Skerman and Riveros (1990) that getting benefit from nitrogen of this species is considerably high. It was also reported (Schnoor, 2002) that *K. scoparia* can be used in contaminated areas, and found that this species can be used on lands irrigated with leakage water.

Although, *P. notatum* and *N. oleander*, which are given in Fig. 1(b), showed an increase of N content in the bodies, the increase was not observed to be as much as the species in Fig. 1(a). Although N is not accumulated the most, *N. oleander* among all the plants is highly resistant to being irrigated with leachate, with a 100% survival rate. It can be said that *N. olander* appears to be a suitable species for use on this kind of land when survival rates and nitrogen accumulation are considered together. Aksoy and Ozturk (1997), also reported this species can be used in contaminated areas as a useful bio-monitor.

In Fig. 1(c), the N content in bodies of three species showing similar responses to leachate; *R. officinalis*, *M. piperita* and *P. peltatum* are shown. Although these plants are observed to accumulate higher amounts of N than the control set, the decelerating increase continues until ½ leachate concentration and all the three plants show a decrease of N accumulation in irrigation with pure leachate. This group of plants seems to reach their tolerance limit, in terms of nitrogen.

As one of the severe environmental challenges that require immediate response, solid waste management, including recycling opportunities, treatment options and disposal methods, most commonly ends up with a landfill site throughout the world. As well as closed landfill sites currently employed ones exert risk to surrounding surface and groundwater bodies. In order to prevent the potential hazards of fresh water sources being polluted with leachate from landfill sites, every single landfill site, closed or employed, should be taken into a rehabilitation and restoration program. These programs should utilize every possible preventive/corrective actions.

This study was conducted in order to search for plant species to be used in rehabilitation and recreational arrangement of landfill sites, aiming to observe applicability of the tested plant species for landscape applications of solid waste landfill areas as sample groups of perennial grass and shrubs plants. Except *Cynodon dactylon*, *Paspalum notatum* and *Pelargonium peltatum*, the plants were able to survive in acceptable rates, although they significantly altered their N balance of their bodies. Among other species, *Nerium oleander* and *Kochia scoparia* are the most appropriate species to be used in this area. *Kochia scoparia* species displayed high visual quality under the conditions of leachate.

Although by employing only these species can not be able to restore/rehabilitate landfills alone, these plants can be utilized as assistive agents of wider projects of nitrogen and heavy metal removal from polluted soil medium. These projects may include irrigation of these plants with collected leachates. Further studies can inspect how effectively these species can be utilized in phytoremediation techniques, constructed wetlands and application of landfill site rehabilitation projects.

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