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Pathogen reduction effects of solar drying and soil application in sewage sludge

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Abstract: The responses of sludge faecal coliforms, *Salmonella,* and *Ascaris lumbricoides* to heat drying, solar dehydration, and inactivation in soil are examined in this study. The presence of *Salmonella* in raw sludge cake after treatment was low, and absent for most of the cases. Likewise, the viable *Ascaris* eggs were not determined because of absent or low prevalence. Faecal coliforms, on the other hand, drastically decreased from 4.2×10^7 MPN g^{-1} Dry Solid (DS) to absence by heat drying. Faecal coliform numbers in solar and non-solar drying treatments were not declined below 1.0×10^3 MPN g^{-1} after drying to 90% DS and also during the storage of 12 weeks. After 6 weeks, faecal coliform and *Salmonella* levels in the soil surface application fell below undetectable limits. The coliform numbers below soil surface fell gradually over 12 weeks and numbers were below undetectable limits at end of the experiment. These results showed that although the solar drying has significant effects on removing pathogenic microorganisms during hot and dry periods, the soil treatment was still necessary for the final complete inactivation. Solar exposure on the soil surface was found to be effective on the elimination of pathogens.

Key words: *Ascaris*, faecal coliforms, *Salmonella*, sewage sludge, soil, solar drying

Güneşte kurutma ve toprağa uygulamanın arıtma çamurlarında patojen giderimine etkisi

Özet: Çalışmada arıtma çamurlarında bulunan fekal koliform, *Salmonella* ve *Ascaris lumbricoides*'in yüksek sıcaklıkta kurutma, güneşte kurutma ve toprak uygulamalarında giderimi incelenmiştir. Ham çamur ve uygulamalardan sonra incelenen örneklerde *Salmonella* varlığı düşük bulunmuştur veya tespit edilmemiştir. İncelenen örneklerde canlı *Ascaris* parazitine, bölgede varlığı ve yaygınlığının düşük olmasından dolayı rastlanmamıştır. Yüksek sıcaklıkta kurutma uygulamasında fekal koliform sayısı 4.2×10^7 MPN g^{-1} kuru ağırlıktan tespit edilemez sayıya inmiştir. Fekal koliform sayısı güneşte ve gölgede kurutma uygulamalarında kuru madde oranı % 90'a ulaştığında ve ardından 12 haftalık depolama süresinde 1.0×10^3 MPN g^{-1} kuru ağırlık altına düşmemiştir. Toprak yüzeyine uygulamada 6 hafta sonra fekal koliform ve *Salmonella* sayısı tespit edilemez sayının altına inmiştir. Toprak içine uygulamada koliform sayısı 12 hafta boyunca yavaş olarak azalmış ve çalışmanın sonunda tespit edilemez seviyeye ulaşmıştır. Sonuçlar güneşle kurutmanın arıtma çamurlarındaki patojenik mikroorganizmaların gideriminde sıcak, kuru dönemde etkili olduğunu, bununla birlikte tam giderim için toprak uygulamasının gerekli olduğunu göstermiştir. En etkili patojen gideriminin toprak yüzeyine uygulama ile sağlandığı tespit edilmiştir.

Anahtar sözcükler: *Ascaris*, fekal koliform, *Salmonella,* arıtma çamuru, toprak, güneşte kurutma

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Introduction

The increase of wastewater treatment plants results from the large quantities of residual sewage sludge. Safe disposal of the sewage sludge is one of the major environmental concerns throughout the world. The widespread disposal alternatives that have been frequently used include soil application, landfill, and incineration (Singh and Agrawal 2008). Land application of the sewage sludge, on the other hand, is suggested to be the most economical sludge disposal method because it combines disposal and recycling. Sewage sludge contains fertilizer nutrients and organic matter, which would have a significant positive impact on the physical properties of the soil and crop yield (Singh and Agrawal 2008).

In Turkey, regulations on sewage sludge for land application were adapted by the 86/278/EEC directive (1986), which encourages the use of sewage sludge in agricultural land. It prohibits the use of untreated sludge on agricultural land and regulates the limit values for concentrations of heavy metals and organic compounds in sludge. There are no regulations or limit values for pathogenic organisms, therefore US EPA limits (1993) for pathogenic organism are frequently used for comparison.

The main concern on the land application of sewage sludge is pathogen transmission, and thus limits, regarding the pathogen amount, were set for the land application of untreated wastes in most countries. The actual species and density of pathogens existing in sewage sludge depend on the health status of the local community and the sewage sludge treatment processes (Sasakova et al. 2005). Furthermore, the survival or inactivation of pathogens in the sewage sludge depends upon a number of factors, such as temperature, moisture content, and competition from indigenous microflora. Other factors, such as predation, pH, sunlight, oxygen, soil type, and texture, also influence the pathogen inactivation.

These microorganisms are extremely sensitive to loss of moisture (Garcia-Orenes et al. 2007), implying that the drying of sludge reduce their numbers. Sludge drying experiment indicates that the number of pathogen significantly reduced when the sludge was dried in either ambient weather condition or in a covered drying hall (Choi et al. 2005; Salihoglu et al. 2007). Zaleski et al. (2005) reported that the number of faecal coliforms and *Salmonella* decreased as the temperature and rate of desiccation increased. The requirements of class A sludge were achieved after 3 to 4 weeks of drying. A number of studies have been carried out to quantify the number of pathogens and indicator organisms in the sewage sludge and also after the land application in soil. The survival of bacterial pathogens up to 36 weeks in stored dried sludge was reported (Gibbs et al. 1997) as well as a lower survival time of less than 6 weeks was reported in the sludge that had been exposed to land application (Nicholsan et al. 2005). Thus, the number of pathogens in sewage sludge could be reduced when the sludge is incorporated into soils or soil surface due to the loss of moisture, solar irradiation, and interaction with soil.

Solar drying of sludge has become an economically feasible technique of sludge stabilisation in the regions where warm and drought weather conditions are naturally available. In contrast to the conventional drying processes, energy demand for evaporation is fully covered by solar energy and electrical energy consumption reduced by more than 4 times (Bux et al. 2002). Even though the dehydration effects of solar drying have been studied extensively, its effects on the survival of pathogenic microorganisms displayed variable results (Choi et al. 2005; Malack-Muhammad et al. 2007; Salihoglu et al. 2007). In this paper, the effects of solar drying and soil application on the removal of sludge pathogens, such as faecal coliform, *Salmonella,* and *Ascaris lumricoides* are tested.

Materials and methods

The sludge used in the experiments was obtained from the Wastewater Treatment Plant of the city of Sakarya in May 2008. The current treatment facility in this plant is capable of treating a flow of 90,000 m^3 day^{-1} in an extended aerobic activated sludge process. After the thickening process, sludge is dewatered by belt pressure filter to produce the end product that is 20% DS. Dewatered sludge obtained from the belt filter was used in the study. Physicochemical characteristics of this sludge are presented in Table 1.

Table 1. Main characteristics of sewage sludge used in the experiment.

Parameter	Mean
Dry matter (%)	18 ± 0.6
pH	7.6 ± 0.1
Conductivity (mS cm^{-1})	1.09 ± 0.1
Organic material (%)	54.6 ± 1.2
Kjeldahl nitrogen (%)	3.34 ± 0.1
Phosphorus (mg kg^{-1})	2710 ± 9.2
Potassium (mg kg^{-1})	5120 ± 10.4
Cd (mg kg^{-1})	2 ± 0.5
Cr (mg kg^{-1})	243 ± 10
Cu (mg kg^{-1})	19 ± 1.0
Ni (mg kg^{-1})	79 ± 3.0
Pb (mg kg^{-1})	34 ± 2.0
Zn (mg kg^{-1})	1435 ± 15.0

In this study, the indicator microorganism in raw sludge and effects of different drying applications were carried out to quantify the sludge for a safe land application. Five pathogen inactivation options, such as heat drying at 80 °C, solar drying on concrete lined bed, drying without solar exposure under sheltered place, solar exposure on soil surface, and soil incorporation just below the soil surface were assessed at weekly intervals during the summer, from June through August, 2008. For quick drying, raw sludge cakes containing 82% moisture were spread to a depth of 2 cm on a concrete bed and dried to 90% DS by frequent tilling in 2 days for solar and 6 days for non-solar drying. After drying process, samples were placed in plastic bags and stored at laboratory conditions.

The soil used in the experiment was 2% sand, 60% silt, and 38% clay, with a silty-clay-loam texture. The air dried soil was sieved through a 2 mm mesh before use. For soil treatment, a certain quantity of dry sludge, equivalent to 36 g kg^{-1} soil, was applied to the soil surface as raw sludge cake at 82% moisture. The same amount of raw sludge cake was added to the below surface layer of soil and then covered by 1 cm soil in a 1.5 L container. Both soil treatments were carried out in triplicates; and thus, 72 soil containers each containing 1 kg of soil were prepared and placed at ambient weather conditions.

Sludge samples obtained before and after the treatment were analysed for the presence of faecal coliforms, *Salmonella*, and viable *Ascaris lumbricoides* eggs. Moisture contents of the dried samples were above 90% before pathogen detection and storage for drying treatment. The pathogens in samples were monitored every week for storage effects during 12 weeks. For determination of pathogens in the soil treatment, sludge cake samples, collected from the soil surface and below top layer, were removed from the soil and subjected to microbial analysis. In all studies, faecal coliform analyses were performed according to the EPA method 1681 (USEPA 2005). Brilliant green bile broth was used as the growth medium. MPNs are expressed per gram DS. *Ascaris* eggs were separately investigated in the sludge samples. To determine the occurrence of *Salmonella* spp., the international standard ISO 6579 (ISO 1993) was used; this test, however, cannot be used for quantification but it only indicates the presence or absence of this micro-organism.

The faecal coliform counts at 90% DS and the end of the experiment were analyses using ANOVA. The results subjected to LSD test to check whether the differences were significant for a significance level of $P = 0.05$. To improve the normality and homocedasticity, the data regarding the coliforms were transformed by $Xi = \log (ni + 1)$ prior to the statistical analysis.

Results

The findings of faecal coliform in raw sewage sludge demonstrated a difference in the reduction of pathogens following different treatment options. As expected, for the heat dried sludge, none of the microorganism was detected in any of the samples analyzed at the beginning and after 12 weeks of storage period. *Salmonella* was not detected in the majority of samples taken from the raw sludge cake and during the 12 weeks monitoring period regardless of the treatment used.

Rapid solar drying on concrete lined bed reduced the count of faecal coliform more than drying without solar exposure did (Figure 1). The initial faecal coliform amount of 4.2×10^7 MPN g^{-1} DS decreased to 1.7×10^5 MPN g^{-1} DS when the dry solid content of

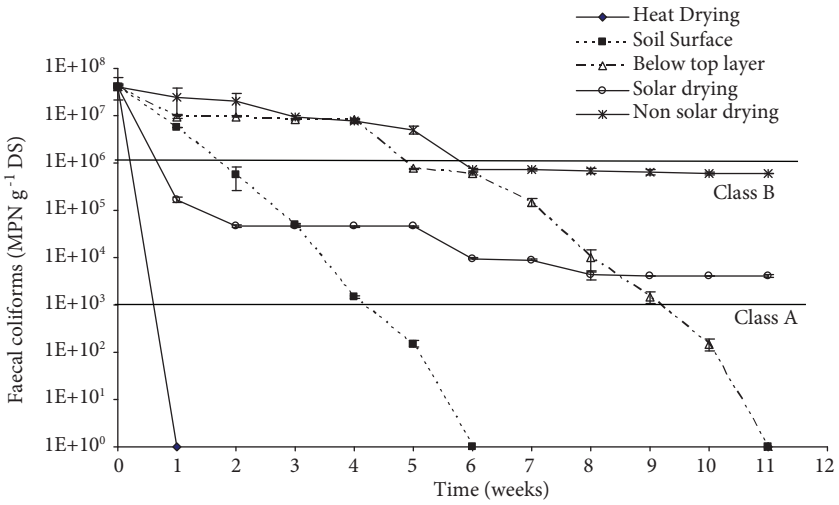

Figure 1. Faecal coliform numbers versus time for sewage sludge dried at heat, solar exposure, non-solar exposure, and soil surface and below soil surface application treatments. Error bars represent standard deviation.

sludge reached up to 90% after 2 days of drying with solar exposure (Table 2). Drying without sunlight exposure was not effective for the faecal coliform inactivation. The faecal coliform counts were 2.4×10^7 MPN g^{-1} DS for the dehydration without solar exposure at the same water content after 6 days (Table 2). Drying of sludge with or without solar exposure in a 2 to 6 days period did not completely inactivate the coliform bacteria. The survival level of the faecal coliform in both drying treatments was similar during 12 weeks of storage (Figure 1), which indicated that storage itself has no inactivation effects. After 12 weeks of storage of dried sludge, faecal coliform was isolated in the both solar ($>10^3$ MPN g^{-1} DS) and non-solar ($>10^5$ MPN g^{-1} DS) dried samples (Table 2).

The amount of faecal coliform bacteria in the fresh sludge cake decreased in time in both sludge samples that were applied to the surface and below the top layer of soil. In the surface sludge application, however, the number of faecal coliform decreased dramatically over time; reduced below Class A level by 5 weeks, and they disappeared after 7 weeks. It seems likely that dehydration, together with solar exposure, in a longer period reduced the water content of the sludge sufficiently impacting the faecal bacteria. In the sludge application below the top layer

Table 2. Faecal coliforms counts in sludge particles dried with heat, solar or non-solar treatment, and inactivated on soil surface or below soil surface.

Treatment	At 90% DS		End of the experiment	
	Mean	S.D.	Mean	S.D.
Heat Drying	0 d	0	0 c	0
Solar drying	2.5×10^4 c	4000	4.1×10^3 b	104
Non solar drying	2.1×10^7 a	152,752	6.0×10^5 a	1315
Soil surface	2.5×10^5 b	1100	0 c	0
Below top layer	1.5×10^4 c	25,166	0 c	0

Values followed by different letters are significantly different for P = 0.05.

of the soil, *faecal coliforms* were survived at least 8 week over Class A limits; possibly in the microsite habitat of sludge. Initial sludge moisture over 82% was suitable for the development of bacteria. The decrease in numbers was gradual over time and the numbers were below undetectable limits after 11 weeks.

The ANOVA results of the faecal coliform count at 90% sludge DS showed that only heat drying significantly reduced the coliform numbers (Table 2). At the end of the experiment, disappearance was achieved by heat drying and soil applied treatment. Drying with or without sunlight exposure did not achieve a complete inactivation (Figure 1, Table 2).

After 4 weeks of studying all the samples, *Salmonella* were below detectable limits in sludge particles, regardless of placement of the samples in the soil; soil surface or below top layer. In regard to the parasitic helmint (*Ascaris lumbricoides*), it was not possible to isolate a viable egg from the raw sludge cake probably because of the low *Ascaris* prevalence at the wastewater collecting area.

Discussion

Survival and inactivation of pathogenic microorganisms depend on many environmental and physicochemical factors, such as the dryness of sludge, pH, the soil type, temperature, exposure to sunlight, exposure to air, and soil moisture, and biological factors including predation, competition, and production of inhibitory substances by soil micro-organisms. Therefore, the reported survival period of sludge microorganism is variable according to the subjected environmental conditions (Gibbs et al. 1997; Estrada et al. 2006; Pourcher et al. 2007).

The results of this study generally indicated that the solar drying on concrete beds decreased the number of sludge pathogens below the Class B limits but not below the limits of Class A (USEPA 1993) when the sludge reached 90% DS. The elimination of sludge pathogens below Class A limits were not achieved during the storage period of 12 weeks after drying. The presence of bacteria in dry sludge indicated that the bacteria were still accessing the moisture for their growth. This observation is in agreement with the findings of Gibbs et al. (1997), who observed that the sludge pathogen survived longer in dried sludge piles. Nonetheless, *Salmonella* was not observed in the stored sludge after 4 weeks. According to the US EPA regulations (1993), the dehydration of sludge dried by solar exposure satisfied the Class B limits, which state that the faecal coliform density must be less than the 10^6 MPN g^{-1} DS. As for the results on faecal coliform, it is not possible to produce Class A sludge, which states that the number of faecal coliform must be less than 10^3 MPN g^{-1} DS. According to the results, further treatments, such as excess pH or high temperature, as proposed by several authors, will be necessary to lower pathogen risks and fulfil the regulations limits (Estrada et al. 2006; Salihoglu et al. 2007).

The results of this study suggest that the bacterial number in sludge particles, excluding soil, indicates the condition that vertical and horizontal migration of faecal coliforms in soil was absent when the dehydrated sludge was applied (Crush et al. 2006). It should be pointed out that coliform numbers were much lower in soil compared to sludge particles in it; which is in agreement with the finding that the presence and persistence of faecal coliform depend on the application dose (Estrada et al. 2004; Heras et al. 2005). These results confirm that physicochemical conditions of the soil and interactions with soil microbiota hastened the coliform inactivation, which was not observed in the case of solar drying treatment.

Spreading on the soil surface rather than mixing in soil gave the best pathogen inactivation in a shorter period (7 weeks, Figure 1). In spite of the low number of faecal coliforms existing in sludge before application, it is known that the pathogen increase their initial number when they find favourable soil conditions, especially moisture (Gibbs et al. 1997; Estrada et al. 2004). Nonetheless, their number decreased below the detectable limits over time, less than 3 months for most of the cases, regardless of their initial number or sludge stabilisation degree (Estrada et al. 2006; Garcia-Orenes et al. 2007; Pourcher et al. 2007).

Heat drying at a high temperature, such as 80 °C, is proved to be best option for rapid decay of pathogen in sludge. However, because of high investment expenses and high energy consumption, heat drying is an expensive process (Bux et al. 2002). Despite the

slow removal of pathogens in soil after sludge application, the soil biota are involved in pathogen reduction processes in sludge amended soil.

The presence and reduction of *Salmonella* in the sludge-soil matrix during summer conditions correspond well with other studies conducted in warmer regions (Estrada et al. 2005). The nonexistence of *Ascaris* in the sludge was considered to be related to the public health status. Similarly, Ben-Ayed et al. (2007) and Ak et al. (2006) reported that the prevalence of intestinal parasites were related to the environmental conditions and socioeconomic level of the population.

Considering the inactivation of sludge pathogen in soil, land application of sewage sludge can be beneficially used as soil or pasture amendment during dry summer periods. Nevertheless, at least 1 month is necessary to restrict the public access and animal grazing after land application. Horswell et al. (2007) reported that periods greater than 6 months are sufficient to reduce the microbial contaminants to the background levels.

Based on the results of the present study and the literature, it is obvious that solar drying and soil application have sufficient inactivation effects for sludge microorganisms. Based on the disinfecting effect of solar drying, spreading on soil surface during dry summer periods is recommended when the vegetation is at minimum for the effective sludge stabilization and land amendment. Following spring grazing could be an effective measure for preventing the risk of disease transmission and to avoid contamination during the application of sludge.

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