ECOLOGICAL TOILETS IN HOT ARID CLIMATES

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Objective To determine the ecological toilet type best suited for the hot, arid study area by evaluating: treatment methods and the destruction of human pathogens in biosolid waste over time, toilet construction and cost, as well as user satisfaction.

Methods We constructed five each of four different ecological toilet types: single and double-vault non-urine diverting (biodegrading) and single and double-vault urine diverting (dehydrating). Biosolid samples were analyzed by multiple-tube fermentation for fecal coliform concentrations and by immuno-fluorescence for Cryptosporidium parvum and Giardia lamblia. A questionnaire was used to assess user satisfaction.

Findings Results indicated that a combination of low percent moisture in biosolids and pH >10 were best to reduce microorganisms when treating biosolid waste. Construction cost and user satisfaction were similar for all toilet types tested.

Conclusions In the hot and dry atmosphere of north central México, study results indicated that the desiccation treatment utilizing either single or double-vault urine-diversion dehydrating toilets was the best ecological toilet system.

Introduction

Ecological toilets require neither water nor sewage infrastructure for their operation and are a viable alternative where water is scarce (1, 2). They have an advantage over the pit latrine, as there is minimum environmental pollution and they have the potential to improve public health by reducing illnesses caused by fecal-oral transmission of pathogens. There are two basic types of ecological toilets based on whether they treat biosolid waste by biodegradation or dehydration. Biodegrading toilets promote pathogen reduction by increasing the temperature of the composting pile to as high as 70C by the action of thermophilic aerobic bacterial growth (3). Dehydrating toilets rely on desiccation and high pH >10, a result of low moisture content <25% and the addition of an alkaline agent (4).

In a previous study (5), we investigated approximately 90 single-vault, ecological toilets to determine the primary mechanism (biodegradation or dehydration) for reducing fecal coliforms in biosolid waste. Results showed that Class A compost (high grade) was present in only 35.8 % of ecological toilets after six months treatment and that the primary mechanism for fecal coliform reduction was found to be dehydration rather than biodegradation, even though the toilets were designed and operated as a biodegradation system. Drier samples had a greater proportion of Class A samples and the variable, low moisture, had an Odds Ratio of 3.6 as a predictor of Class A biosolids (5).

Results from this prior study suggested that it was important to determine which type of ecological sanitation systems was best suited for a particular environment. To determine this, we constructed five each of four different ecological toilet types: single and double-vault non-urine diverting (biodegrading) and single and double-vault urine diverting (dehydrating). Analyses of the four systems were based on the reduction fecal coliforms as well as Cryptosporidium and Giardia, toilet construction and cost, as well as user satisfaction. Cryptosporidium and Giardia were chosen as indicator organisms because of their high prevalence in the study area (6).

MATERIALS AND METHODS

The study area was located on the México/USA border in Cd. Juárez, Chihuahua México, a city of approximately 1.4 million inhabitants. The study site included three peri-urban communities that lacked municipal water and sanitation services. Most participants had pit latrines and were of low socio-economic status, with an average yearly income of US$ 3,300. A survey on user satisfaction was completed after three and six months of use.

All systems were constructed on-site with locally available materials. The four systems selected were: (1) single-vault biodegrading, (2) double-vault biodegrading, (3) single-vault dehydrating, and (4) double-vault dehydrating. Training sessions were conducted for all participating families. Single-vault biodegrading toilets had passive solar panels to heat the composting chamber. Sawdust and toilet paper were added as soak materials for the urine and feces in the chamber to adjust the moisture content and the carbon:nitrogen (C:N) ratio. Since the biodegradation of pathogens was aided by aerobic bacteria growth, the biosolid waste was mixed each week to oxygenate the composting heap. The double-vault biodegrading toilet was similar to the single-vault biodegrading toilet, except that it had two processing chambers, one of which was used for long-term composting (Fig. 1a).

The single-vault, dehydrating toilet used a urine-diverting pedestal to decrease the amount of moisture that entered the processing chamber (Fig. 1b and c). Urine was diverted to a soak-pit filled with gravel and sand located outside the toilet. A mixture of soil and lime was added to assist the desiccation process and raise the pH >10, which aids in pathogen reduction (4). The double-vault dehydrating toilet was similar to the single-vault dehydrating toilet but had separate vaults, so there was a physical barrier between fresh fecal matter and dehydrating waste.

Construction of all ecological toilets was under the supervision of a local construction engineer. From a construction point of view, there were two basic designs, one for the single-vault and one for the double-vault toilets. The type of pedestal added after construction determined whether a toilet was urine diversion or not. The overall dimensions (width, length, height) of the two systems were: double-vault base 170 x 200 x 60cm and superstructure 170 x 130 x 200cm; single vault base 120 x 190 x 60cm and superstructure 120 x 130 x 200cm.

Biosolid waste samples were collected and analyzed at approximately two, four, and six months after initiation. In the single-vault toilets, at two months, the accumulated pile was pulled down into the secondary processing area, which separates it from new waste additions. In the biodegrading toilets, this began a four-month period during which the composting pile must be aerated by stirring 1-2 times per week. After this four-month period in the secondary processing area, the biosolid waste was removed for disposal. In the double-vault systems, the pedestal was moved to the other vault after two months, which physically separated the composting biosolid waste from new additions.

Fecal coliform concentrations were estimated using the multiple tube fermentation with A-1 Medium (7) as described in the USEPA Standard Method 9221 E (8). Some pathogens, especially those forming spores or eggs may be less affected by biodegradation and desiccation and can survive for much longer times (3, 10). Therefore, we also monitored Cryptosporidium oocysts and Giardia cysts by the immuno-fluorescence technique (6) utilizing the Merifluor detection kit (Meridian Diagnostics, Inc, Cincinnati). The number of oocysts per microscopic sample (10 µl) was semi-quantified by averaging five microscopic fields and scoring samples as high (> 10), low (1--10), or negative (0). For the purpose of comparison between the different ecological sanitation systems, average numbers were adjusted for sample dilution, microscopic magnification, and original percent moisture in samples.

All data were analyzed utilizing SPSS statistical software and Chi square or t tests were employed to determine significant correlations where this was possible. For the purpose of some statistical analyses, microorganisms were dichotomized as positive or negative and data from single and double-vault toilets were combined for the biodegrading and dehydrating systems.

RESULTS AND DISCUSSION

Four types of ecological toilets were designed and constructed to determine which system was better suited to the hot and arid study area. Toilet types and designs were based on those described previously (11). Basic differences in design features of the biodegrading and dehydrating systems are outlined in Table 1. There were two forms for both the biodegrading and dehydrating toilets, the single and double-vault structures.

Table 1. Feature comparison of biodegrading versus dehydrating systems.

	Biodegrading	Dehydrating
Urine diverting	No	Yes
Soak materials	Yes	No
Lime/soil mixture	No	Yes
Aeration (mixing)	Yes	No

The cost for the building materials for the single-vault systems was approximately US$ 510 and for the double-vault systems was approximately US$ 600. Even though the double-vault system was a larger structure, there were few differences in the construction cost because all systems had metal doors, metal roof, and metal stairs, which were major expenses. Those toilets with urine diversion also had urinals with a cost of US$22 each. All systems were equipped with inexpensive (US$10) low-water use hand washing facilities outside the structure and consisted of a plastic pail with a water faucet (Fig. 1d).

For the biodegrading systems, there was a mean percent moisture of approximately 25% by the fourth month (Figure 2). This moisture level was already too low for efficient biodegradation, which requires moisture levels between 40-60% (12, 13). On the other hand, the dehydrating system had only 7% moisture at four months, which is appropriate for a desiccating system. Thus, in terms of moisture content, the dehydrating system was the better choice.

The mean pH of the two systems was < 8 for the biodegrading and approximately 10 for the dehydrating system (Figure 3). The increased pH in the latter was the result of the addition of lime. Since high pH values are known to promote pathogen kill (4), the dehydration system was again the better choice.

The third measure studied was the presence of microorganisms over time and included fecal coliforms, Cryptosporidium, and Giardia. After six months, the biodegrading systems had a similar level of fecal coliform content compared to that of dehydrating systems, 7.3 log versus 7.0 log (Figure 4). Both systems had approximately a two-fold log reduction in fecal coliforms between two and six months. This reduction was probably the results of desiccation rather than biodegradation due to the low moisture content, which was below the optimal level required for biodegradation.

There was a major decrease in Cryptosporidium detected in the biodegrading system compared to that of the dehydrating system, 67% to 50% positive versus 46% to 0% positive after six months (Figure 5). This dramatic decrease was likely the result of increased pH in the dehydrating system, since we have already indicated that the biodegrading system was not optimized with respect to moisture content. For Giardia, there was also a decrease but less pronounced, 100% to 83% versus 100% to 68% positive after six months. Although this assay does not measure viable oocysts and cysts, it is a valid indicator for their absence, which is the objective in this study. Based on the microorganism indicators used, the dehydrating system fared better especially for treating Cryptosporidium.

When all parameters (percent moisture, pH, and microorganisms) were considered, the better choice for treating biosolid waste in this study area was consistently the dehydrating system over the biodegrading system. The environmental setting was a key variable related to determining that dehydration was better for treating biosolid waste. Summer months are hot and dry and winter months sunny, dry, and cool. With a year round dry climate, moisture levels in the compost heap are lower than would be expected in humid, tropical environments. Thus, the biodegrading toilets did not perform well since the composting pile rapidly lost moisture to below the critical level required to support microbiological growth.

Another indication for lack of biodegradation activity was the pile temperature. In an active composting pile, aerobic thermophilic bacteria increase the temperature of the pile above that of ambient temperature and at higher temperatures promote pathogen kill. In this study, on no occasion was the pile temperature measured above that of the ambient temperature. Based on these two lines of evidence, moisture content and pile temperature, in the dry atmosphere of north central México, the desiccating toilet was the most appropriate choice.

All ecological toilet users were very satisfied with their new toilets regardless of the type. The main variables that users considered important were the absence of flies and odor. Compared to their previous system of pit latrines, the new systems had no odor and only a few flies. Some users preferred the biodegrading toilets because they did not want to treat the biosolid waste with lime, since they planned to use the composted waste on non-edible plants. With respect to single versus double vault design, the double vault was determined more appropriate since there was a clear and undisturbed separation of biosolids in the second chamber during the four-month treatment. The double vault also provided more room for the installation of the urinal in the dehydrating toilets. Disadvantages of the double-vault design were a slight increase in cost and a larger site required for construction.

ACKNOWLEDGEMENTS

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References

1. **Esrey S, et al.** *Ecological Sanitation*. Stockholm: Sida, 1998.
2. **Harper P, Halestrap L**. *Lifting the lid*. London: Biddles, Ltd, 1999.
3. **EPA**. *Process design manual: Land application of sewage sludge and domestic septage*. Cincinnati: US Environmental Protection Agency; 1995 September. Report No: EPA/625/R-95/001.
4. **Rynk R**. *On-farm composting handbook*. Ithaca: Cooperative Extension, NE Regional Agricultural Engineering Service, 1992.
5. **Redlinger T, et al.** Survival of fecal coliforms in dry-composting toilets. *Appl Environ Microb* 2001,**67**(9):4036-4040.
6. **Redlinger T, et al.** Hyper-endemic *Cryptosporidium* and *Giardia* in households lacking municipal sewer and water on the US/Mexico border. *Am J Trop Med Hyg* 2002, **(in press)**.
7. **Strandridge J, Delfino J**. A-1 medium: alternative technique for fecal coliform organism enumeration in chlorinated wastewaters. *Appl Environ Microbiol* 1981,**42**:918.
8. **Clesceri L**, Greenberg A, Eaton A, editors. Standard Methods for the examination of water and wastewater. 20th ed. Baltimore MD: APHA, United Book Press; 1998.
9. **EPA**. *A plain English guide to the EPA part 503 biosolids rule*. Washington DC: Office of Wastewater Management, 1994.
10. **Redlinger T, et al.** Ecological Sanitation Toilets: An evaluation of pathogenic microorganisms in biosolid waste. *Bull WHO* 2002,**(under review)**.
11. **Winblad U, Kilama W**. *Sanitation without water*. London: MacMillan Education, LTD, 1985.
12. **Gray K, Sherman K, Biddlestone A**. A review of composting Part 2--The practical process. *Process Biochem* 1971,**6**:22-28.

13. **Haug R**. *Compost engineering principles and practice*. Ann Arbor: Ann Arbor Science Publishers, Inc, 1980.

1a 1b

1c 2d

Figure 1: Features of ecological toilets. Panel a: Double-vault biodegrading toilet with passive solar panels; Panel b: Urine diverting pedestal and wall mounted urinal. Molds for casting were obtained from César Añorve, CITA (Centro de Innovación de Tecnología Alternativa, Cuernavaca, México); Panel c: Top view detail of urine diverting pedestal; Panel d: Hand washing facility mounted to exterior of super structure.

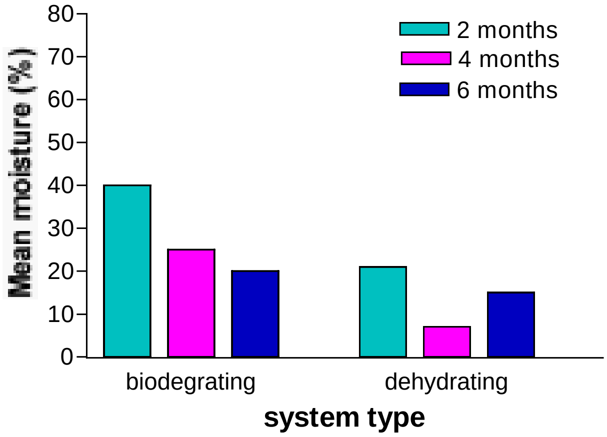

Figure 2. Percent moisture in biodegrading versus dehydrating systems.

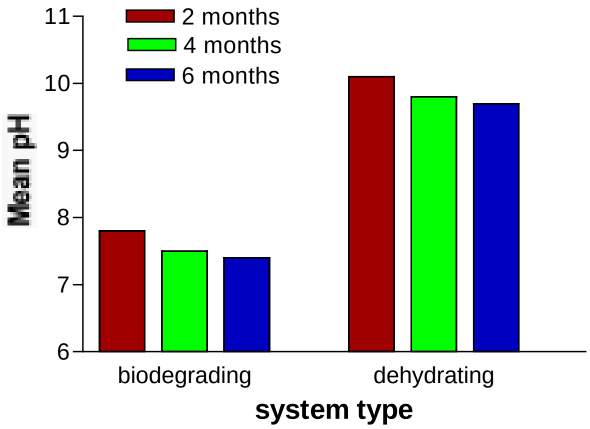

Figure 3. Mean pH values in biodegrading versus dehydrating systems.

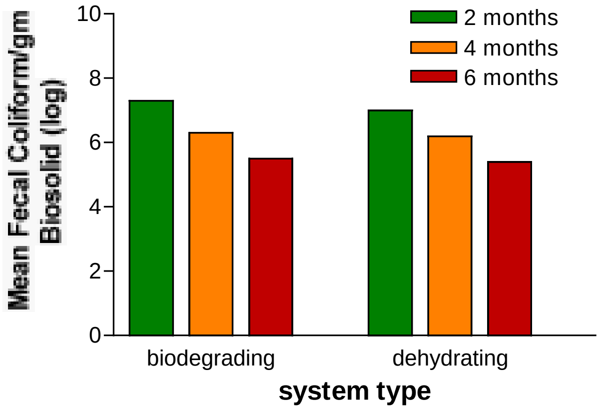

Fig. 4. Fecal coliform reduction in biodegrading versus dehydrating systems.

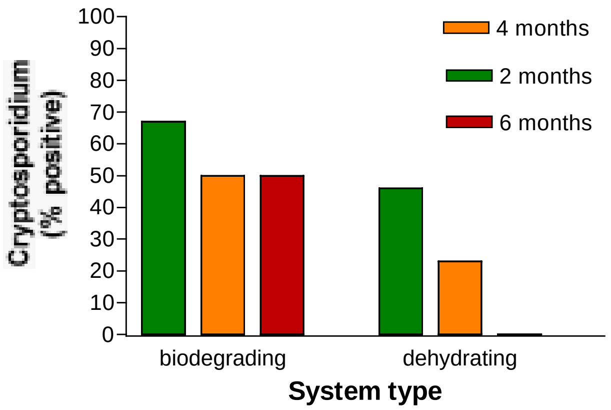

Figure 5. Cryptosporidium in biodegrading versus dehydrating systems.

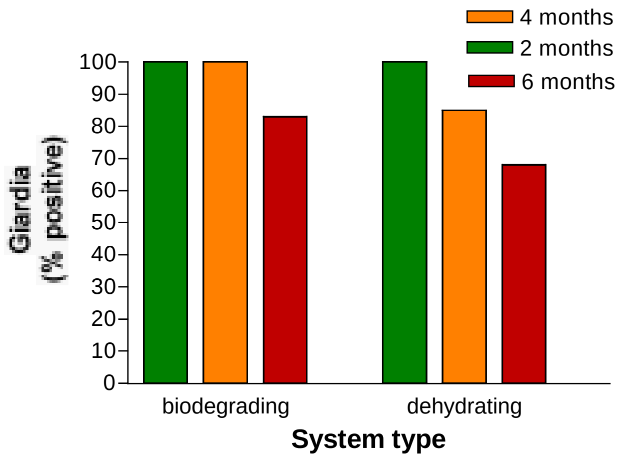

Figure 6. Giardia in biodegrading versus dehydrating systems.