NITROGEN REMOVAL FOR ON-SITE SEWAGE DISPOSAL: FIELD EVALUATION OF BURIED SAND FILTER/GREYWATER SYSTEMS

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ABSTRACT

The nitrogen removal associated with buried sand filter/greywater systems, patterned after RUCK system designs, was assessed in a field laboratory and two full-scale systems in Rhode Island. Specifically, the study tested the ability of buried sand filters to support nitrification and the suitability of household greywater as a carbon source for denitrification. The buried sand filter/greywater systems removed approximately 50% of the total nitrogen in household wastewater before the wastewater entered the soil absorption field. Nitrification within the buried sand filters was a major limiting factor to complete nitrogen removal, with filters generally providing 50-80% nitrification. Denitrification rates of 100% were routinely observed using greywater as a carbon source and a rock tank with a three day retention period as an anaerobic environment. Rock-free tanks with a one day retention period were also assessed as an anaerobic environment, providing an average of 74% denitrification. Buried sand filter/ greywater systems show promise as a nitrogen removal system for on-site sewage disposal.
KEYWORDS. Sewage, Filters, Nitrogen removal.

INTRODUCTION

On-site sewage disposal systems are used by approximately 1/3 of all homes in the United States as the method of treating and disposing of household wastewaters (Canter and Knox, 1985). Conventionally designed systems, which consist of a buried septic tank followed by a subsurface soil absorption system, are not designed to remove nitrogen from the wastestream. Innovative nitrogen removal systems for household wastewater disposal need to be developed for unsewered areas where water quality is threatened by nitrogen loading.

Several on-site sewage disposal systems have been designed to achieve nitrogen removal through a two phase approach of nitrification followed by denitrification (Andreoli et al., 1979; USEPA, 1980; Laak et al., 1981; Lamb et al., 1990). In the nitrification phase, ammonium-N (NH_4^+-N) in septic tank effluent is oxidized to nitrate-N ($N0_3^-$-N) under aerobic conditions. In the denitrification process, $N0_3^-$-N is subsequently reduced to nitrogen gases in an anaerobic zone with the provision of a supplemental organic carbon source.

One approach to nitrogen removal has been to separate the blackwater and greywater wastestreams within the household. Most of the nitrogen from a household comes from the toilet wastewaters (blackwater), while much of the organic carbon is found in the kitchen and laundry wastewaters (greywater) (Siegrist et al., 1976). Laak (Laak et al., 1981; Laak, 1982, 1986) developed a system, termed the RUCK system, that was designed to nitrify blackwater in a buried sand filter and then mix the nitrified blackwater with greywater in an anaerobic tank. The greywater provided the carbon source for denitrification within the anaerobic tank. Final disposal of the effluent was in a conventional soil absorption system.

Although RUCK systems have been installed in several locations in the United States, the nitrogen removal capacity under field conditions has received little study. To better understand nitrogen removal within the RUCK system, several independent studies were undertaken in New Jersey and Rhode Island beginning in 1984/1985. In New Jersey, fifteen residential and three commercial full-scale RUCK systems were constructed and monitored on a quarterly basis, each for three years (Windisch, 1990). At the University of Rhode Island, a field laboratory was constructed in 1986 to evaluate a buried sand filter/greywater system (modeled after the RUCK system) in comparison with a conventional septic tank/soil absorption field system and a recirculating sand filter system (Lamb et al., 1987, 1990). Two full-scale residential RUCK systems built in 1987/1988 in Charlestown, Rhode Island were also monitored by the University of Rhode Island. While the RUCK system has undergone a series of design changes to increase total-nitrogen (total-N) removal and to minimize construction costs, the above nitrogen removal processes appear to be consistent in the Rhode Island and New Jersey systems.

The specific objectives of the research presented here were to:

- Assess the effectiveness of the buried sand filter for nitrification;
- Characterize the suitability of household greywater as a carbon source for denitrification; and
- Assess the total-N removal associated with buried sand filter/greywater systems.

Results from both the field laboratory and the full-scale systems in Rhode Island are presented, as well as comparisons with the residential systems in New Jersey.

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METHODS

FIELD LABORATORY

Three 1/5 scale replicates of a buried sand filter/greywater system were constructed at the University of Rhode Island as part of a study to compare nitrogen removal systems to conventional septic tank/soil absorption field systems (Lamb et al., 1987; Lamb et al., 1990). Each of the three replicates received 115 L of septic tank effluent per day delivered in 12 equal increments. To ensure even wastewater distribution between replicates, pressure dosing was employed using orifice flow manifolds which were routinely monitored for leaks.

The three buried sand filter/greywater system replicates were modeled after designs established by Laak for the RUCK system (Laak et al., 1981; Laak, 1982; Laak, personal communication). Each replicate consisted of a buried sand filter, an anaerobic tank, and a soil absorption trench with greywater providing an added carbon source to the anaerobic tank. The sand filters were designed according to RUCK system specifications and were approved by the licensed Rhode Island RUCK system engineer during construction. Each sand filter was 1.22 m × 1.22 m × 1.22 m deep and was comprised of alternating layers of sand (effective diameter of 0.25 mm, uniformity coefficient of 4.0) and washed stone (2-5 cm), with aeration tubes and patented percolation indrains installed in the sand layers. Each filter received septic tank effluent at a hydraulic loading rate of approximately 76 L/m^2-day (1.85 gal/ft^2-day). At the field laboratory, the sand filter influent was from the total wastestream (greywater + blackwater) in contrast to actual RUCK systems where the influent is designed to contain only the blackwater portion of the flow.

Anaerobic tanks were used to denitrify sand filter effluent. From June 1987-June 1989 buried, baffled rock tanks provided the anaerobic environment. The rock tanks had a total void volume of 1.82×10^3 L and were designed to provide approximately a three day retention period. The volume of liquid held in the tank (liquid storage capacity) was 500 L. Tank media was 2-5 cm washed stone. In June 1989, to evaluate a system which would reduce the space and cost requirements of the RUCK system, the size of the anaerobic environment was decreased by replacing the rock tanks with 230 L rock-free dosing tanks (liquid storage capacity of 180 L). Retention time in these tanks was approximately one day. Effluent from both types of anaerobic tanks passed into soil absorption trenches for final treatment and disposal.

During the study, greywater (comprised of kitchen and laundry wastewaters) was obtained from a nearby home and was dosed to the anaerobic tanks 12 times/day. Two different proportions of greywater relative to the total wastestream were evaluated. From June 1987-March 1988 greywater constituted 25% of the total wastestream entering each replicate, while from March 1988-May 1990 greywater constituted 40% of the total wastestream.

The field laboratory began operation in June 1986. Samples were taken on a tri-weekly basis for the study period June 1987 to December 1988, and on a monthly/bimonthly basis from January 1989 to May 1990. All system components were sampled concurrently, with above-grade risers located at discrete points to permit sampling of all tanks and filters. Samples were analyzed for temperature, pH, and alkalinity upon collection (USEPA, 1979). Subsequent analyses included: TKN (total Kjeldahl nitrogen) by the block digestor method (Eastin, 1978; USEPA, 1979); ammonium-N (NH_4^+-N) by the colorimetric salicylate-hypochlorite method (Bower and Holm-Hansen, 1980); and nitrate-N + nitrite-N (NO_3^--N + NO_2^--N) by cadmium reduction using an automated Technicon Auto-Analyzer (Technicon Industrial Systems, 1973; Lambert and Oviatt, 1986) and an automated Rapid Flow Analyzer (Alpkem Corp., 1986). In this article, NO_3^--N and NO_2^--N concentrations are combined and reported as NO_3^--N. Total organic carbon (TOC) was determined on selected tank and filter samples by the combustion method (USEPA, 1979).

FULL-SCALE SYSTEMS

Two full-scale RUCK systems (D and K) located along a coastal pond in Rhode Island were selected for this portion of the study. These residential systems were located in a similar geologic setting (stratified glacial outwash sands and gravels) as the field laboratory. Both systems were constructed in 1987/1988 according to design criteria established by Laak (Laak et al., 1981; Laak, 1986; Laak, personal communication), with the supervision and approval of the licensed RUCK system engineer in Rhode Island.

Based on engineering records and observations of effluent flow from the household, System D was plumbed such that greywater included all non-toilet wastes from the household. Engineering records for System K specified this same type of flow separation; however, observations of effluent flow from the household indicated that the greywater in System K represented only kitchen and laundry wastes. Both houses had reduced flush toilets (13.25 L/flush). Since water meters were not installed at either house, the proportion of greywater in the total household wastestream was estimated at 80% for System D and 60% for System K. This proportion was estimated from: a water use survey of each household; published studies on water use per appliance (USEPA, 1980); measured total-N concentrations in greywater and blackwater; and the average total-N concentration expected in household wastewater (Andreoli et al., 1979; Canter and Knox, 1985).

Samples were collected on a monthly basis from each home. System D was sampled from June 1988 to May 1989 and System K was sampled from November 1988 to May 1989. Both homes were occupied for at least three months before sampling commenced. During study periods, samples were taken of blackwater septic tank effluent, greywater septic tank effluent, sand filter effluent, and rock tank effluent. Following collection, each sample was analyzed for: temperature, pH, and alkalinity (USEPA, 1979); NO_3^--N by ion chromatography (USEPA, 1984); and TKN by the block digestor method (Eastin, 1978; USEPA, 1979; Bower and Holm-Hansen, 1980). Greywater samples were additionally analyzed for TOC (USEPA, 1979). Greywater samples from 13 of the RUCK systems in the New Jersey Pinelands study were also analyzed for TOC, with samples collected semi-annually for 2.5 years.