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# An Investigation for the Need of Secondary Treatment of Residential Wastewater when Applied with a Subsurface Drip Irrigation System

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**ABSTRACT**

Two subsurface drip irrigation (SDI) systems were installed and monitored at two sites in Tennessee. These locations were residential developments each served by a septic tank effluent pump (STEP) collection system, a recirculating media filter (fine gravel media), and SDI dispersal. At both locations, SDI research plots were established to receive primary treated (septic tank effluent) and secondary treated (recirculating media filter effluent) wastewater. In close proximity to randomly selected SDI emitters, soil samples were extracted. Soil cores were analyzed to determine hydraulic conductivity, and pore water samples were analyzed for nitrate, total nitrogen, total carbon, and total phosphorus. Results indicate that the primary-treated side had lower hydraulic conductivity values, higher nitrate and higher total nitrogen levels than the secondary-treated side and the background soil. Interestingly, the primary-treated side had less total carbon, and the background phosphorus concentration was twice that of the primary and secondary treated sides. The primary effluent application site showed a decrease in concentration for all constituents with increased depth. Secondary treatment does result in a higher quality effluent but is not needed when applying effluent with a SDI.

Subsurface drip irrigation (SDI) has been widely adopted as an alternative effluent dispersal method for sites with shallow restrictive soil features. Pressurized hydraulic networks ensure uniform effluent distribution across the soil adsorption area. This improves the treatment potential by maximizing the contact of effluent with soil particle surfaces. It is a common practice to provide secondary treatment to wastewater that is to be dispersed via SDI. Pre-treatment is usually provided by an aerobic treatment unit or a packed-bed media filter. This 'requirement' for pre-treatment is largely based on protecting the emitters, the in-line devices that control the effluent emission rate from the drip tubing. The need for secondary pre-treatment is debated because good design and management practices have been shown to protect the emitters by providing effluent filtration and by frequent flushing of the drip tubing. Certainly, providing secondary treatment prior to dispersal takes much of the treatment responsibility away from the soil, especially when SDI is used in soils with shallow restrictive features. However, it is thought that the improvement in application uniformity may overcome the limitations in the soil depth required to renovate the effluent.

The primary hypothesis of this study is that secondary treatment is not needed to adequately purify residential wastewater, when SDI is used. This study will prove or disprove this hypothesis by analyzing the soil and soil solution near and below SDI emitters. Hydraulic conductivity will be used to determine differences in soil physical properties related to the application of secondary-treated and primary-treated effluent. Further, the soil solution will be sampled for nitrate-nitrogen ($NO_3^-$ -N), total nitrogen (TN), total phosphorus (TP), and total carbon (TC) to determine differences in water quality beneaths these treatments.

# METHODS AND MATERIALS

**Site Descriptions**

This research was conducted at two residential subdivisions, Jackson Bend (JB), located in Blount County, Tennessee and Crescent Glen (CG), located in Rutherford County, Tennessee. Each subdivision is serviced by a decentralized wastewater management system that consists of a Septic Tank Effluent Pump (STEP) collection system, a recirculating media filter for secondary treatment, and subsurface drip irrigation for effluent dispersion.

At each location, two 93 $m^2$ SDI research plots were constructed, each with 305 m (1,000 ft) of drip tubing, divided into twenty 15-m (50 ft) laterals. The drip tubing had a nominal diameter of 1.27 cm (0.5 in), and the pressure compensated emitters were rated at 2.3 L $hr^{-1}$ (0.62 gal $hr^{-1}$). One plot received septic tank effluent (STE) and the other received recirculating sand filter effluent (RSFE). The application rate was 4.1 L $m^{-2}$ (0.1 gal $ft^{-2}$). Thus, each field receives 757 L (200 gal) per day every day. When sampling began, the reseach plots at CG had been in operation for five years and the JB plots had been in operation for three years.

STE was collected by installing a diversion valve in the effluent sewer just prior to the secondary treatment. The soil in JB is primarily a sandy loam and is 120-240 cm to groundwater. JB is made up of high-end housing with large lots. The soil in CG is primarily a clay loam with about 60 cm to bedrock. The homes in CG are mainly starter homes with small lots.

**Sample Collection and Analysis**

Four rounds of samples (soil cores), representing four seasons, were taken from each of the four plots. Background soil samples were collected from just ouside of the plots and were used as controls. Soil cores were collected in a similar manner as Jnad (2001a, 2001b). Soil samples were collected with a coring device and transported to the laboratory for analyses. The cores had 5 cm diameters and were 7.5 cm long. Samples were obtained from two depths; 30 cm below the emitter level, and 60 cm below the emitter level. At each depth, samples were collected at six locations relative to the emitter. Each core location was labeled with a number 1-14 depending on its location relative to the drip emitter. Locations 1-12 were located near the emitter while locations 13 and 14 were the control samples (30 and 60 cm depths, respectively). The odd numbered cores correspond with samples taken from the 30 cm depth and even numbered cores correspond with samples taken from the 60 cm depth. Samples 3 and 4 were collected 30 and 60 cm below the drip emitter, other samples were taken 30 cm to either side of the drip lateral, and then 30 cm down the drip lateral. The same pattern was repeated at 60 cm below the drip lateral fig 1). A total of 14 cores were taken from each plot during each sampling event. A much more detailed outline of the sampling procedure can be found at Hillenbrand (2010).

Each boring was initially excavated to a depth of 25 cm so that the coring sampler could extract a sample with the 30 cm depth in the middle of the core. Once the first core was taken, a loose soil sample was collected for soil solution extraction. The hole was then extended to a depth of 56 cm and a core sample and another loose soil sample was collected. The same sampling process was repeated for the control samples.

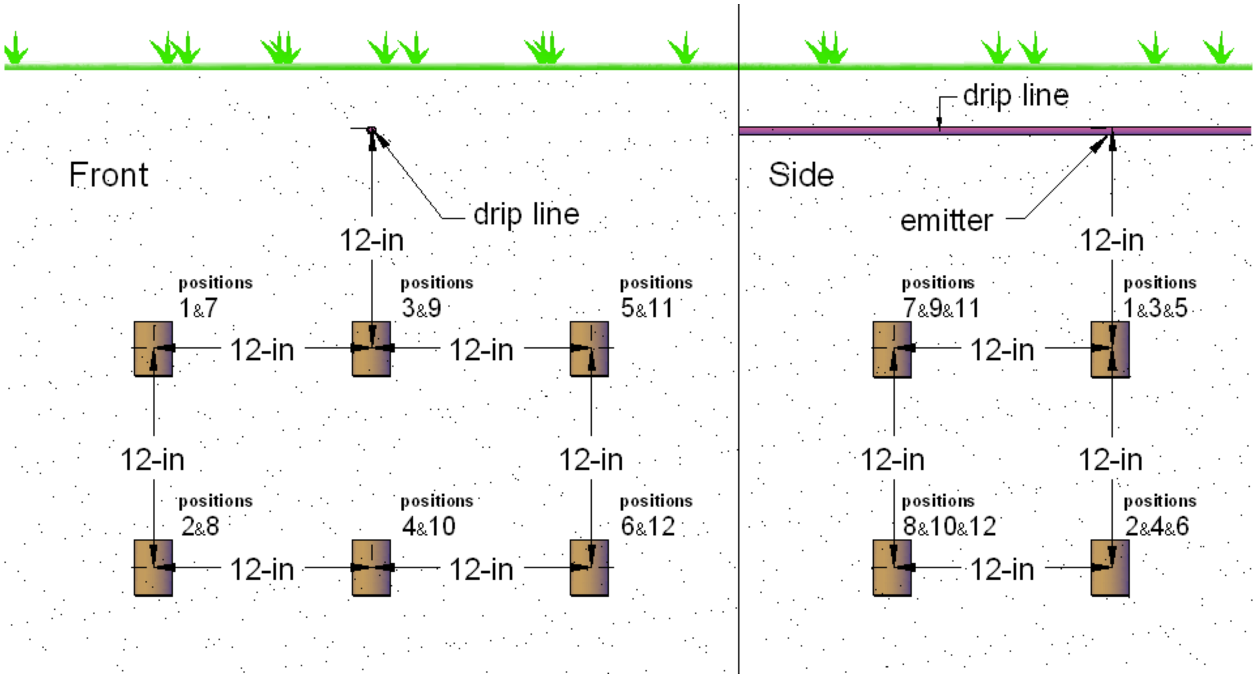


Figure 1. Positions of soil cores relative to drip line and emitter.

**Physical Analysis**

A falling head permeameter setup was used to determine the saturated hydraulic conductivity (hydraulic conductivity) of each core sample. Fourteen permeameters were installed on a rack to run all 14 samples from each sampling event at one time. Preliminary testing showed that the saturated hydraulic conductivity for the samples ranged from 0.3 to 0.8 cm/day. The cross sectional area in inches of the standpipe (a), the cross sectional area of the sample in inches (A), the length of the sample in inches (L), time in seconds (t), and the heights of the water levels, in inches, relative to the bottom of the sample (H1 and H2) were used to calculate the hydraulic conductivity for each core.

**Soil Solution Extraction**

Deionized water was used as a solvent to extract the soil solution. Moist soil samples, containing approximately 100 g (dry weight), were added to bottles that contained 50 g of deionized water. Parallel samples were dried at 105°C for 24 hours and weighed to determine the moisture content. This method provided a means to collect a soil solution volume, which could be reliably collected, and the final solution concentration could be corrected for dilution (Klute, 1986). The concentrations are listed on a mg-constituent per kg-soil basis.

Total Kjeldahl phosphorus (TKP) and total Kjeldahl nitrogen (TKN) and soluble nitrogen were determined by the block digestor method (APHA, 2005). Total organic carbon (TOC) was determined using the combustion method (APHA, 2005). TKN measures the organic nitrogen and ammonium in the sample. Soluble nitrogen, which includes nitrate and nitrite, was determined by using the difference in the TKN method and the persulfate oxidation method (APHA, 2005). Most soil elemental analysis does not include soluble nitrogen due to the ease of the TKN method and the concentration of nitrate and nitrite in most soils is very limited. Because wastewater is being applied to this soil, the concentrations of soluble nitrogen should be greater and is important to this study. Nitrogen is reported on an "as N" basis.

**Statistical Analysis**

The experimental design was a randomized block design – split-plot (RBD-SP). The analysis of variance (ANOVA) using the mixed models procedure for RBD split-plot design (SAS version 8.0, University of Tennessee, Knoxville) was used to analyze the data. Each location (JB and CG) was a whole plot, the split plots were the main treatments (STE, RSFE and Control). Sampling depth became a second factor the split-plot design. The data were blocked on sampling date. Log transformations were performed on Ksat, $NO_3^-$, TP data, and a square root transformation was used on the TN data. The estimated means reported are the back transformed means. Significance was determined at the 0.05 level. The data are listed in Table 1.

## RESULTS AND DISCUSSION

**Hydraulic Conductivity**

At JB, there was no significant difference in hydraulic conductivity between the STE and RSFE treatments; however the RSFE side did have a significantly lower Ksat than the control. The estimated Ksat values for STE, RSFE, and the Control are as follows: 0.041, 0.036, and 0.073 cm/day respectively. The Ksat differences for 30-cm and 60-cm depths were not significant (0.049 and 0.050 cm/day, respectively).

At CG, there was no significant difference in the hydraulic conductivity between the RSEF and STE (0.042 and 0.027 cm/day respectively). The STE at a depth of 60 cm was significantly lower than the Control at a depth of 30 cm, but not significantly different than RSFE at either 30 cm or 60 cm, or STE at 30 cm.

**Nitrate-Nitrogen**

At JB, there was no significant difference for nitrate between the STE, RSFE, and Control treatments. Depth was a significant factor for nitrate concentration at JB with the concentration getting higher nearer the emitter (3.970 mg/kg at 30 cm and 2.602 mg/kg at 60 cm). The nitrate concentrations for the RSFE and Control were much lower at CG than at JB, but the CG STE nitrate concentration was nearly twice the JB STE nitrate concentration (11.300 mg/kg and 5.804 mg/kg, respectively). Depth did not matter at CG but the greatest difference in depth occurred with the CG STE samples. The concentration of nitrate at 30 cm below the emitter for the STE side at CG was 14.6 mg/kg, but by 60 cm below the emitter, the concentration was 8.725 mg/kg.

**Total Carbon**

At JB, TC was lower in the STE as compared to the RSFE and Control treatments but not significant due to the variability in the data. At CG, the TC differences were smaller ranging from 25.6 to 29.8 mg/kg for the STE, RSFE and Control treatments, all of these were less than the RSFE and Control Concentrations from JB. The depth did not seem to impact the concentration of TC found in the soil at either location.

### Total Nitrogen

At JB, the TN concentration was not significantly different between the three treatments. The treatment means ranged from 6.4 to 8.4 mg/kg. At JB, the Control at the 30-cm depth had a significantly higher concentration of TN than at the 60-cm depth, but these concentrations were not significantly different compared to the STE and RSFE samples and either depth. The STE-TN concentrations at CG were significantly different from the RSFE and Control concentrations (9.80, 2.80, and 2.81 mg/kg resp.). Depth at CG was not a significant factor.

### Total Phosphorus

At JB and CG, there was no significant difference in TP between the three treatments. The control samples from JB at the 30-cm depth were significantly higher than the STE and RSFE samples. The means for RSFE at JB are higher than the means for STE but were not significant. The RSFE samples at CG have a lower TP concentration than the STE and Control samples.

## CONCLUSION

The purpose of this study was to evaluate two strengths of wastewater (STE and RSFE) being applied by SDI to determine the need for secondary treatment. The purpose was not to evaluate the performance of SDI as a whole. SDI augments the soil's ability to treat wastewater but its full potential may be diminished by the use of secondary treatment. Physical and chemical properties of the soil were measured to make the comparison. It was found that the pore water in the soil that had been irrigated with the low strength wastewater (RSFE) was of slightly higher quality than the pore water in the STE side. At Jackson Bend, the nitrate-nitrogen, total carbon, total nitrogen, and total phosphorus concentration levels were statistically the same. At Crescent Glen the nitrate-nitrogen and total nitrogen concentration leverls were significantly higher in the STE treated areas but the total carbon and total phosphorus concentration levels showed no significant differences. The benefits of a secondary treatment are not significant enough to make it necessary when using a SDI. The soil provides much of the same treatment as a pre-treatment system, and SDI dispersal systems are designed to fully utilize these characteristics.

#### Acknowledgments

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**Table 1. Modeling results for hydraulic conductivity and soil solution samples taken during investigation. Comparisons are made in three clusters. Cluster 1 – all controls, RSFE, and STE independent of depth; Cluster 2 – all cores at 30 cm vs. all cores at 60 cm independent of treatment; and Cluster 3 – interaction of treatment and depth.**

**SAS Output for Jackson Bend.**

| Treatment | Ksat (cm/d) | | $NO_3^-$ ppm | | TC ppm | | TN ppm | | TP ppm | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate | Std Err | Estimate | Std Err | Estimate | Std Err | Estimate | Std Err | Estimate | Std Err |
| Control | 0.073 a | 0.019 | 2.780 a | 1.146 | 42.674 a | 13.130 | 6.428 a | 2.861 | 0.422 a | 0.163 |
| RSFE | 0.036 b | 0.010 | 1.997 a | 0.826 | 39.132 a | 12.564 | 7.022 a | 2.898 | 0.263 a | 0.121 |
| STE | 0.041 ab | 0.010 | 5.805 a | 2.080 | 13.560 a | 14.016 | 8.435 a | 3.659 | 0.120 a | 0.081 |
| 1 (30 cm) | 0.049 a | 0.012 | 3.970 a | 0.905 | 33.442 a | 10.876 | 8.603 a | 2.655 | 0.292 a | 0.747 |
| 2 (60 cm) | 0.050 a | 0.012 | 2.602 b | 0.629 | 30.135 a | 10.797 | 6.051 b | 2.227 | 0.214 b | 0.063 |
| Control 1 | 0.068 a | 0.024 | 4.657 a | 1.927 | 43.521 a | 13.982 | 8.947 a | 3.579 | 0.547 a | 0.200 |
| Control 2 | 0.078 a | 0.024 | 1.586 b | 0.779 | 41.826 a | 13.433 | 4.325 b | 2.488 | 0.318 b | 0.141 |
| RSFE 1 | 0.037 a | 0.010 | 2.040 ab | 0.862 | 42.668 a | 12.763 | 7.263 ab | 3.052 | 0.279 ab | 0.126 |
| RSFE 2 | 0.035 a | 0.012 | 1.955 ab | 2.305 | 35.596 a | 12.660 | 6.785 ab | 2.950 | 0.247 ab | 0.119 |
| STE 1 | 0.043 a | 0.011 | 6.321 a | 1.977 | 14.136 a | 14.139 | 9.693 ab | 4.052 | 0.133 ab | 0.086 |
| STE 2 | 0.038 a | 0.011 | 5.327 ab | 1.977 | 12.984 a | 14.139 | 7.264 ab | 3.508 | 0.107 ab | 0.079 |

**SAS Output for Crescent Glen.**

| Treatment | Ksat (cm/d) | | $NO_3^-$ ppm | | TC ppm | | TN ppm | | TP ppm | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate | Std Err | Estimate | Std Err | Estimate | Std Err | Estimate | Std Err | Estimate | Std Err |
| Control | | | 0.691 b | 0.348 | 25.690 a | 15.758 | 2.816 b | 2.213 | 0.154 a | 0.123 |
| RSFE | 0.042 a | 0.007 | 0.336 b | 0.151 | 29.813 a | 15.440 | 2.803 b | 2.144 | 0.067 a | 0.047 |
| STE | 0.027 a | 0.007 | 11.297 a | 3.735 | 26.765 a | 15.441 | 9.800 a | 4.010 | 0.195 a | 0.133 |
| 1 (30 cm) | 0.052 a | 0.009 | 1.674 a | 0.456 | 27.914 a | 15.496 | 4.705 a | 2.772 | 0.131 a | 0.073 |
| 2 (60 cm) | | | 1.462 a | 0.404 | 26.931 a | 15.442 | 4.635 a | 2.751 | 0.122 a | 0.069 |
| Control 1 | 0.080 a | 0.023 | 0.739 b | 0.416 | 24.646 a | 16.289 | 2.657 b | 2.209 | 0.153 a | 0.127 |
| Control 2 | | | 0.646 b | 0.375 | 26.735 a | 15.951 | 2.980 b | 2.339 | 0.155 a | 0.128 |
| RSFE 1 | 0.047 ab | 0.008 | 0.273 b | 0.141 | 29.989 a | 15.534 | 2.967 b | 2.220 | 0.068 a | 0.047 |
| RSFE 2 | 0.038 ab | 0.008 | 0.408 b | 0.181 | 29.637 a | 15.494 | 2.644 b | 2.095 | 0.066 a | 0.047 |
| STE 1 | 0.030 ab | 0.008 | 14.610 a | 5.380 | 29.108 a | 15.540 | 9.953 a | 4.068 | 0.214 a | 0.148 |
| STE 2 | 0.024 b | 0.009 | 8.725 a | 3.140 | 24.422 a | 15.495 | 9.648 a | 4.006 | 0.177 a | 0.123 |