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Evaluation of Drip Irrigation Emitters Distributing Primary and Secondary Wastewater Effluents

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Abstract

Drip irrigation is a reliable and efficient way to deliver water to the soil; however, drip emitter clogging is a major concern when irrigating treated wastewater. Four types of drip irrigation emitters from three manufacturers were analyzed over a one-year period to monitor the incidence of clogging and its effect on irrigation uniformity. A controlled laboratory experiment was conducted using two different types of pressure compensating emitters designed for reclaimed wastewater, one type of non-pressure compensating emitter designed for reclaimed wastewater, and one type of non-pressure compensating agricultural emitter designed for potable water applications. Emitters of each type distributed tap water, primary treated septic tank effluent, and secondary treated sand filter effluent. Emitter flow rates were measured each month to identify clogged or flow restricted emitters. Some clogging was seen in each type of emitter over the course of the experiment and emitter flow rates fluctuated over time, suggesting that clogging was gradual and often incomplete. Many of the emitters exhibited a cyclical flow rate indicating that clogging was reversible. The emitters distributing septic tank effluent exhibited the most significant reduction in flow. The most severely clogged emitter experienced a reduction of 63% after one year of irrigation with septic tank effluent. Secondary treatment using the sand filter showed the least clogging in all four types of emitters. One of the reclaimed wastewater emitter types experienced an average reduction in flow of 1% while the other two actually increased in flow by1% and 4% after one year of irrigation with effluent from a sand filter. Water quality appeared to have a more pronounced effect than did emitter type. The effect of wastewater type on emitter discharge was +3.3% for tap water, -9.4% for septic tank effluent, and -0.3% for effluent from secondary sand filtration. While the agricultural drip emitters experienced a significant negative impact after one year of operation the three drip emitters designed for distributing septic tank effluent and reclaimed wastewater showed little clogging and a high degree of uniformity.

Keywords: Drip irrigation; Emitter clogging; Micro irrigation; On-site wastewater treatment; Trickle irrigation

Introduction

Drip irrigation has been utilized for wastewater distribution and reuse where soil conditions prohibit traditional types of wastewater dispersal such as leach fields and mound systems. Drip irrigation offers a solution where other soil treatment systems are inappropriate due to a seasonally high water table, shallow dense soil layer, vegetative cover, space constraints, or other site limitations. The goals of drip dispersal are to attain unsaturated flow, encourage lateral movement through capillary action rather than gravitational flow, and distribute the effluent over the entire application area to promote physical, chemical and biological processes of the soil. Many advantages of distributing treated wastewater with drip irrigation have been established including water conservation, nutrient uptake, ground water protection, pathogen reduction and public safety [1-3]. Clogging of emitters is a major concern in drip irrigation systems because of high levels of suspended solids, organic matter, and nutrients (N and P especially) in treated wastewater effluents. Previous studies have sought to determine the causes and prevention of emitter clogging [4-10]. Causes of clogging can be divided into three main categories: (1) physical, caused by suspended solids; (2) chemical, caused by precipitation reactions; and (3) biological, caused by growth and metabolism of microorganisms; i.e., biofilm formation [11]. Emitter clogging is usually the result of two or more of these processes working in concert [12]. In response to previous research findings, the manufacturers of drip systems have made numerous modifications to emitter design and other system components to prevent emitter clogging. A filtration system to remove suspended solids from the effluent prior to dispersal is now a required component of all drip systems. These are in line systems with 120, 150 or 200-mesh screen. The frequent automatic flushing of these filters is essential for proper operation. Filtration alone will not, however, adequately prevent clogging of the emitters. Scanning electron micrographs indicate that particles small enough to pass through a 120-micron filter were trapped by biofilm growing in the emitter flow pathway [13]. They found accumulation of the small particles lead to the formation of agglomerates of cells and solid particles and the eventual clogging of the emitters. Drip emitters are now designed to produce turbulent water flow inside the chamber. This reduces particle settling and discourages biofilm attachment to the interior walls. A flushing velocity of 0.30-0.61 m sec-1 (1-2 ft sec-1) must be maintained or periodically introduced in the piping network to flush out settled particles and remove slimes and biofilms [14].

In spite of these improved strategies, emitter clogging continues to be a concern with wastewater irrigation. The hydraulic loading regimen of the drip irrigation system is designed based on the assumption that each emitter is distributing the same amount of water per dosing cycle. Emitter clogging is the main cause of discharge variation within the irrigation system [15]. The coefficient of uniformity (CU) shown in equation 1, can be used to describe the spatial uniformity of the drip irrigation system [16,17].

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$$CU = \left(1 - \frac{\sum_{i=1}^{n} |q_i - q_{ave}|}{\sum_{i=1}^{n} q_i} \right) 100 \qquad (1)$$

where qi = individual emitter flow rate, qave = mean emitter flow rate, and |qi-qave| = absolute deviation from the mean. The CU classification is ranked as >89% excellent, 80-89% good, 70-79% fair, and <70% poor. Even a few clogged emitters can greatly reduce the uniformity of water application [18,19] and a drip irrigation system with non-uniform water distribution may fail to operate as designed. Water quality has been identified as the main factor associated with emitter clogging. Capra and Scicolone [20] found a strong correlation between emitter discharge and pH, total suspended solids (TSS), and Biochemical Oxygen Demand (BOD5). Increasing treatment levels to reduce suspended solids and organic matter can improve emitter function. Sand filters can be effective at reducing BOD5 and total suspended solids [21], transforming ammonia to nitrate, removing nitrogen via denitrification [22], and neutralizing pH [23]. Sand filters have been used to treat domestic sewage, food processing waste and industrial waste [24]. Chlorination has also been shown to reduce emitter clogging and is recommended to help prevent development of slimes and biofilms [25].

The purpose of this research was to determine the relationship between wastewater quality and the performance of drip irrigation emitters. Four types of emitters were evaluated. Three types of emitters were designed for use with treated wastewater and the fourth was designed for agricultural irrigation with potable water. The emitters were tested by tracking the flow rates as they discharged tap water, septic tank effluent, and effluent from a sand filter over a one-year period.

Experimental

This study used a laboratory scale drip irrigation setup with 12 lines of drip tubing, each 3.7 m in length. Four different types of wastewater drip tubing were selected for analysis and two sources of wastewater, (i) primary septic tank effluent, and (ii) secondary wastewater effluent from sand filtration, were discharged through the drip emitters. A third source, tap water, was used as control. Three laboratory scale septic tanks were established using a protocol described by Peeples and Mancl [26]. The effluent characteristics, analyzed at the start of the experiment, are given in Table 1.

Two septic tanks were loaded at 24 hr cycles with approximately 57 L tap water, 500 mL primary sludge and 250 mL of 0.363 M ammonium chloride. The primary sludge was acquired from the Southerly Wastewater Treatment Plant (Columbus, Ohio). The third tank matched all aspects of the protocol except that the primary sludge and NH4Cl were not added. This tank served as the control. BOD5 and TSS were analyzed using Standard Methods 5210 B and 2540 D [27]. Ammonia was measured using Quickchem Method number 12-107-06-2-A.

At 24-hour intervals, the effluent from one of the septic tanks was discharged into a sand filter for secondary treatment. The sand filter consisted of a cylindrical polyethylene container, 0.79 m high and 0.55 m in diameter filled with 76 cm of sand. The sand had an effective size of 0.5 mm with a uniformity coefficient of 4. After passing through the sand filter, the effluent was transferred to a dosing tank that was identical to the septic tank in size and design. The effluents from the second septic tank and the tap water control tank were transferred to their respective dosing tanks directly, with no further treatment. Each dosing tank contained a ¼ h.p. (0.18 kW) submersible pump that delivered 0.06 L s-1 of effluent through 0.03 m clear flexible tubing to a Netafim Low Volume Control Zone (LVCZ) unit. The LVCZ combines a 24 V solenoid controlled valve, a 100-micron disc filter and a 138 kPa (20 psi) pressure regulator into a single unit. Each LVCZ unit was connected to a 0.10 m PVC manifold with four 0.01 m male adapters to direct the wastewater into four separate drip lines, one drip line for each of the four different types of emitters (Figure 1). The pressure at the PVC manifold was 90 kPa (13 psi). Drip irrigation tubing, 3.7 m in length, was connected over the 0.01 m adapters to another identical manifold where the remaining effluent was collected and returned to the dosing tanks. The velocity through the drip line tubing was 0.46 m s-1 (1.5 ft s-1). The irrigation water temperature was maintained at ambient room temperature, fluctuating between 23 and 25°C.

Four different types of drip irrigation tubing and emitters were examined.

Type 1: Netafim Bioline; a pressure compensating drip line for wastewater: A pressure compensating diaphragm emitter spaced 0.61 m (24 in) on center and impregnated with the biocide Vinyzene. The nominal flow rate is 3.4 l/h at 7-60 psi.

Type 2: Geoflow PC Wasteflow; a pressure compensating drip line for wastewater: A pressure compensating turbulent flow emitter spaced 0.61 m (24 in) on center with the root intrusion preventing ROOTGUARD (Treflan), and the bactericide Ultra Fresh DM-50 in the dripper line. The nominal flow rate is 2.0 l/h at 7-60 psi.

Type 3: Geoflow NPC Wasteflow; a non-pressure compensating drip line for wastewater: A non-pressure compensating turbulent flow emitter spaced 0.61 m (24 in) on center with the root intrusion preventing ROOTGUARD (Treflan), and the bactericide Ultra Fresh DM-50 in the dripper line. The nominal flow rate is 3.9 l/h at 20 psi with a CV of 0.05.

Type 4: Eurodrip GR: a non-pressure compensating drip line with emitter spaced 0.3 m (12 in) on center for traditional agricultural and horticultural irrigation applications. This drip line was not designed to distribute wastewater. The nominal flow rate is 4.0 l/h at 15 psi with a CV of 0.03.

A Netafim Miracle AC 12 Irrigation Controller maintained the irrigation schedule. This unit controlled the solenoid valves in each Netafim LVCZ unit and the dosing pumps. The controller was programmed to sequentially irrigate all emitter types with each effluent for 10 min, four times each day, seven days a week.

To evaluate emitter performance, an initial flow rate was measured for each emitter in the system prior to beginning the experiment. The flow rate was determined by measuring the volume of effluent over a fixed unit of time. After the irrigation dose was initiated, plastic cups were placed directly under each emitter and effluent was collected for 120 s. This procedure was repeated each month during the one-year experiment. The emitter flow rate data were analyzed using the Microsoft Excel analysis of variance (ANOVA) statistical program. The

Wastewater Source	Characteristics			
	BOD_5 (mg/L)	TSS (mg/L)	Ammonia (mg/L)	pH
Septic Tank Effluent	147	55	18	6.5
Sand Filter Effluent	0.5	3	1	7.2

Table 1: Wastewater Effluent Characteristics.

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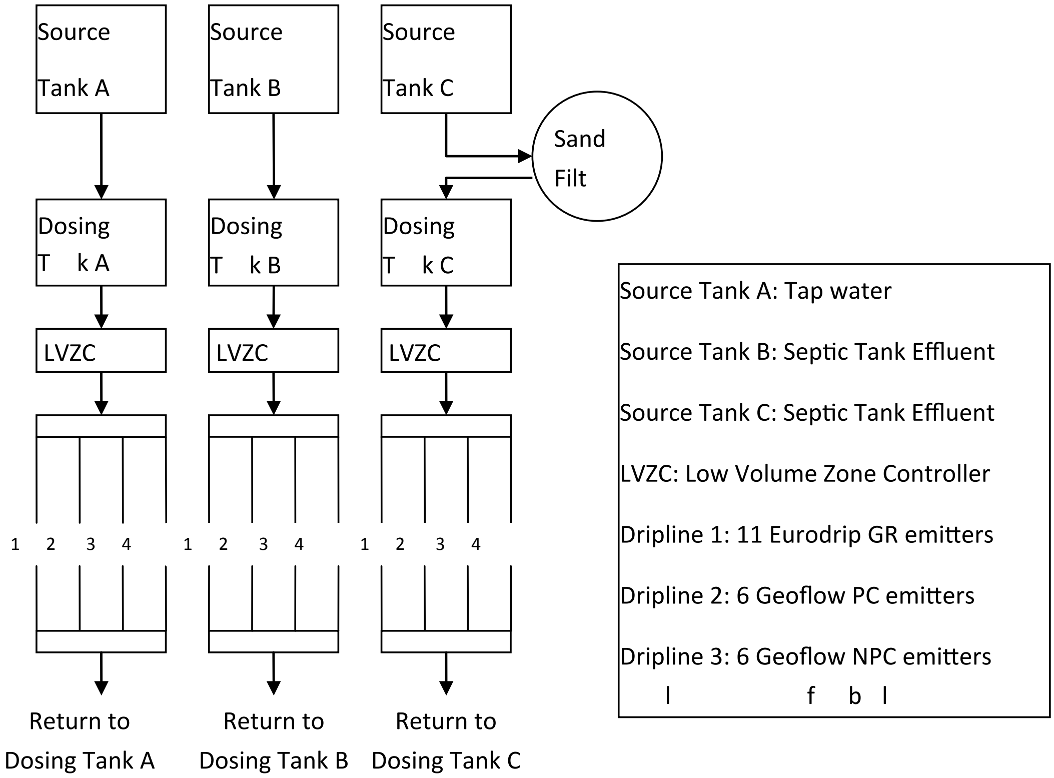

Figure 1: Laboratory Drip Irrigation Layout.

variables were flow rate change over time versus influent wastewater quality.

Results and Discussion

Eurodrip gr emitters

The initial and final flow rates and relative changes over a one-year period for each emitter type are listed in Tables 2-6. The emitter position indicates the sequence of emitters in the drip tubing. Emitter position was not considered a variable in this study. Water pressure and velocity were considered constants because of the short length of each lateral. After one year of continuous irrigation the control emitters distributing tap water showed no signs of clogging. The flow rates of emitters distributing septic tank effluent were reduced by 16% overall, with the most severe reduction of 63% for emitter 7. The flow rates of the emitters distributing sand filter effluent were reduced by an average of 3%. The standard deviation of the overall reduction in flow was greatest for the Eurodrip GR emitters distributing septic tank effluent.

Geoflow pc emitters

The Geoflow PC emitters distributing tap water showed no overall signs of clogging. However, emitter #2 experienced a flow reduction of 7%. The emitters distributing sand filter effluent showed no significant clogging with the exception of emitter 2. All of the emitters distributing septic tank effluent showed reduced flow rates with an average reduction of 12%. The standard deviation of the emitters distributing septic tank effluent was also the highest of this group.

Geoflow npc emitters

The Geoflow NPC emitters distributing tap water and sand filter effluent showed no signs of clogging overall. The flow rates of emitters distributing septic tank effluent were reduced by an average of 6%. The standard deviation of average reduction in flow for emitters distributing septic tank effluent was nearly double the other two emitter types in this group.

Netafim bioline emitters

The Netafim emitters showed little sign of clogging after one year of continuous operation with the exception of emitter 5, distributing septic tank effluent. The average flow rate change for Netafim emitters was positive regardless of wastewater quality. As with the other three groups, the standard deviation of the average flow reduction was highest for those emitters distributing septic tank effluent.

Recovery of clogged emitters

A gradual reduction in flow rate followed by a partial recovery was observed in emitters of each type (Table 7). The maximum flow reduction occurred after eight to ten months for the Eurodrip GR emitters 4, 5 and 6 distributing septic tank effluent. For the emitters Geoflow PC 1 and 3, Geoflow NPC 1 and 3, and Netafim 4, all distributing septic tank effluent, the maximum flow reduction occurred between six and ten months. A partial or complete recovery of emitter flow rate was transiently observed in most cases. The recovery of partially clogged emitters has been observed in other laboratory studies [28] as well as in field applications using lagoon wastewater [3]. It is plausible that biofilm growth inside the emitter constricted the passageway, trapped debris that would otherwise pass through the emitter, and resulted in the observed flow reduction. The start of each irrigation cycle experienced a surge velocity and pressure as the irrigation pumps were turned on, which may have caused biomass and trapped debris to be flushed out, thus resulting in the partial recovery of emitter flow rates.

Emitter Position	**Tap Water**			**Septic Tank Effluent**			**Sand Filter Effluent**		
	Initial (L/h)	**Final (L/h)**	**% Change**	**Initial (L/h)**	**Final (L/h)**	**% Change**	**Initial (L/h)**	**Final (L/h)**	**% Change**
1	2.52	2.64	5	2.54	2.7	2	2.7	2.61	-3
2	2.64	2.85	8	2.52	2.7	7	2.7	2.79	3
3	2.52	2.64	5	2.7	2.79	3	2.7	2.34	-13
4	2.64	2.76	5	2.55	1.95	-24	2.64	2.61	-1
5	2.46	2.61	6	2.37	2.25	-5	2.79	2.85	2
6	2.61	2.79	7	2.46	1.68	-32	2.79	2.73	-2
7	2.55	2.7	6	2.58	0.96	-63	2.91	2.67	-8
8	2.64	2.79	6	2.55	1.56	-39	2.82	3	6
9	2.58	2.7	5	2.46	1.86	-24	2.82	2.43	-14
10	2.67	2.7	1	2.46	2.49	1	2.88	2.85	-1
11	2.67	2.79	4	2.61	2.4	-8	2.85	2.76	-3
Average	2.59	2.72	5	2.53	2.12	-16	2.78	2.69	-3
Std. Deviation			1.7			20.9			6

Table 2: Initial and Final Flow Rates of Eurodrip GR Emitters for One Year. Three sets of 11 emitters with one set receiving tap water, one set receiving septic tank effluent, and one set receiving effluent from a sand filter.

Emitter Position	Tap Water			Septic Tank Effluent			Sand Filter Effluent		
	Initial (L/h)	Final (L/h)	% Change	Initial (L/h)	Final (L/h)	% Change	Initial (L/h)	Final (L/h)	% Change
1	1.32	1.32	0	1.2	0.99	-18	1.35	1.35	0
2	1.35	1.26	-7	1.32	1.26	-5	1.32	1.14	-14
3	1.29	1.32	2	1.23	1.11	-10	1.41	1.41	0
4	1.29	1.32	2	1.26	1.23	-2	1.35	1.41	4
5	1.26	1.35	7	1.23	0.99	-20	1.29	1.23	-5
6	1.23	1.32	7	1.38	1.14	-17	1.35	1.41	4
Average	1.29	1.32	2	1.27	1.12	-12	1.35	1.33	-1
Std. Deviation			4.7			6.8			6.2

Table 3: Initial and Final Flow Rates of Geoflow PC Emitters for One Year. Three sets of 6 emitters with one set receiving tap water, one set receiving septic tank effluent, and one set receiving effluent from a sand filter.

Emitter Position	Tap Water			Septic Tank Effluent			Sand Filter Effluent		
	Initial (L/h)	Final (L/hr)	% Change	Initial (L/h)	Final (L/h)	% Change	Initial (L/h)	Final (L/h)	% Change
1	2.04	2.01	-1	1.95	1.77	-9	1.89	1.95	3
2	1.89	1.92	2	1.92	1.68	-13	1.92	2.04	6
3	1.86	1.89	2	1.83	1.71	-7	2.01	2.13	6
4	1.86	1.92	3	1.92	1.89	-2	2.01	2.13	6
5	1.98	2.1	6	1.92	1.77	-8	2.01	2.01	0
6	1.98	2.07	5	1.92	1.92	0	2.04	2.13	4
Average	1.94	1.99	3	1.91	1.79	-6	1.98	2.07	4
Std. Deviation			2.3			4.3			2.2

Table 4: Initial and Final Flow Rates (ml/min) of Geoflow NPC Emitters for One Year. Three sets of 6 emitters with one set receiving tap water, one set receiving septic tank effluent, and one set receiving effluent from a sand filter.

Emitter Position	Tap Water			Septic Tank Effluent			Sand Filter Effluent		
	Initial (L/h)	Final (L/h)	% Change	Initial (L/h)	Final (L/h)	% Change	Initial (L/h)	Final (L/h)	% Change
1	3.18	3.3	4	3.09	3.3	7	3.39	3.36	-1
2	3.21	3.18	-1	3.12	3.21	3	3.21	3.24	1
3	3.18	3.24	2	3.06	3.21	5	3.33	3.45	4
4	3.15	3.15	0	3.09	3.12	1	3.3	3.33	1
5	3.24	3.24	0	3.21	3.06	-5	3.33	3.45	4
6	3.21	3.36	5	3.15	3.3	5	3.3	3.3	0
Average	3.20	3.25	2	3.12	3.2	3	3.31	3.36	1
Std. Deviation			2.2			3.9			1.9

Table 5: Initial and Final Flow Rates (ml/min) of Netafim Emitters for One Year. Three sets of 6 emitters with one set receiving tap water, one set receiving septic tank effluent, and one set receiving effluent from a sand filter.

Emitter Type and Position	Flow Rates (ml/min)						
	Month 0	Month 2	Month 4	Month 6	Month 8	Month 10	Month 12
Eurodrip GR #4	43	47	42	26	21	8	16
Eurodrip GR #5	40	44	37	26	24	7	26
Eurodrip GR #6	41	43	36	19	15	28	31
Geoflow PC #1	20	21	20	19	18	7	16
Geoflow PC #3	21	23	19	10	8	19	18
Geoflow NPC #1	33	34	30	29	28	6	30
Geoflow NPC #3	31	32	29	19	26	13	29
Netafim #4	52	55	51	46	50	52	52

Table 6: Changes in Flow Rates of Septic Tank Effluents over 12 Months.

Emitter Type	Mean Flow Rate % Change	Final CU (%)	Rating
Eurodrip GR	-9.5	86.9	Good
Geoflow PC	-7.1	90.5	Excellent
Geoflow NPC	-1	90	Excellent
Netafim	2	96.13	Excellent

Table 7: Flow Rate Changes and Coefficient of Uniformity Values for Each Emitter Type.

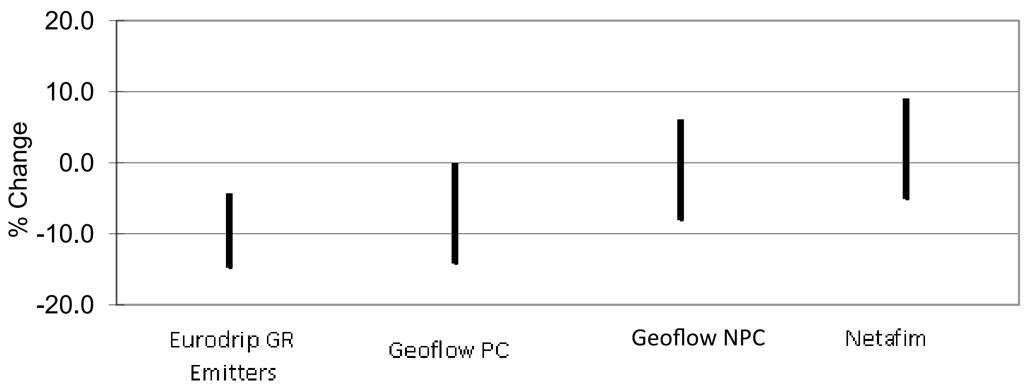

Figure 2: The 95% Confidence Intervals for Each Emitter Type.

Overall emitter performance evaluation

The initial and final flow rate changes of each emitter type for all three effluent types are listed in Table 7. The Eurodrip GR emitters show the greatest reduction in flow while the three wastewater emitters flow rates change ranged from -7% to + 2% of their initial values.

The CU values calculated for the four emitter types, after one year of service, are shown in Table 7. The CU for the agricultural emitters was good (80-89%), while the CU for the wastewater emitters was excellent (>89). The extent of clogging in certain emitters was greater than in others; however, each type of wastewater emitter maintained a high level of uniformity overall. This indicates that clogging in the Geoflow PC, Geoflow NPC and Netafim emitters did not negatively impact the overall performance of the irrigation system.

Analysis of variance for emitter type

The results of the ANOVA analysis for emitter type based on initial and final flow rates indicated that emitter type is a significant variable in determining emitter clogging at the 95% confidence level. Using the initial and final flow rate data, the single factor ANOVA analysis returned a P-value of 0.037, an F critical value of 2.77 and an F calculated value of 3.01. The 95% confidence intervals for each emitter type show that the mean flow was more reduced in the Eurodrip GR as compared to Geoflow PC, Geoflow NPC, and Netafim emitters (Figure 2).

Analysis of variance for wastewater type

The influence of wastewater type on emitter discharge was +3.3% for tap water, -9.4% for primary septic tank effluent, and -0.3% for secondary sand filter effluent. The results of the ANOVA analysis for effluent type based on initial and final flow rates indicated that effluent type was also a significant variable in determining emitter clogging at the 95% confidence level. Using the initial and final flow rate data the single factor ANOVA analysis returned a P-value of 0.000129, an F critical value of 3.1 and an F calculated value of 12.9. The septic tank effluent was detectably different from the tap water and sand filter effluent. The tap water and sand filter effluent were not detectably different from each other. The 95% confidence intervals for each effluent type show the clear distinction between the mean of the septic tank effluent and the mean of the other two effluent types (Figure 3).

Conclusions

The purpose of this study was to analyze four different drip emitters with respect to their resistance to clogging and to determine the relationship between effluent treatment levels and emitter performance. This experiment utilized a bench scale irrigation system to simulate a full-scale field application. The drip lines, emitters and filters used in this study were identical to those of a full sized system; however, due to space limitations some design modifications and adjustments were necessary. After one year of dispersal, individual emitters experienced

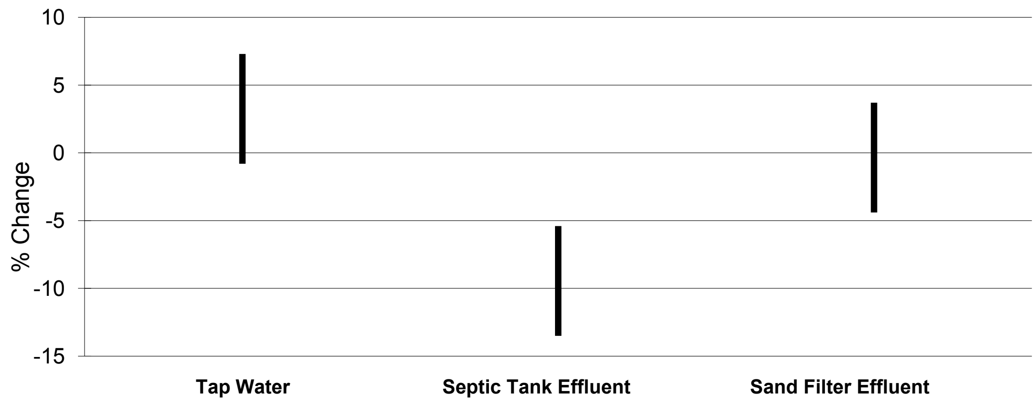

Figure 3: The 95% Confidence Intervals for Each Effluent Type.

discharge variations from slight increases to severe reductions of up to 63%. The agricultural emitters showed the greatest extent of clogging. The emitters specifically designed for discharging wastewater showed less clogging and maintained the highest CU rating after one year of continuous operation. Secondary treated wastewater from a sand filter provided the best performance for all emitter types. Primary septic tank effluent was also successfully distributed with drip irrigation emitters that were designed for use with treated wastewater. The emitters designed for traditional agricultural/horticultural irrigation applications, performed satisfactorily with sand filter effluent but experienced a high degree of clogging with septic tank effluent. The analysis of variance between emitter type and change in emitter flow rate (Figure 2) showed that emitter type is a significant variable in emitter clogging incidence, but there was no detectable difference between the three wastewater emitters at a 95% confidence level. The analysis of variance between wastewater type and emitter flow rate (Figure 3) showed that wastewater type (i.e., wastewater quality) is a more significant variable than emitter type. The extent of emitter flow reduction was highest for the primary septic tank effluent while the secondary treated effluent was not detectably different from tap water at the 95% confidence level. This study suggest that using drip irrigation emitters that are specifically designed for distribution of wastewater and treating the wastewater using a sand filter will reduce the extent of emitter clogging and improve overall distribution uniformity.

The clogging process of the drip emitter was not linear over time or unidirectional. Emitter flow rates fluctuate with time and emitters have the ability to self clean during normal startup and dose cycles. This self-correcting ability was most evident with the three wastewater drip emitters distributing the higher quality wastewater effluents. The traditional agricultural drip emitters distributing septic tank effluent showed the least ability to self clean after clogging had begun.

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