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Dripline Flushing Velocities for SDI

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Abstract. *The velocity of dripline flushing in subsurface drip irrigation (SDI) systems affects system design and cost, management, performance and longevity. A study was conducted at Kansas State University to analyze the effect of four flushing velocities (0.23, 0.30, 0.46 and 0.61 m/s) and three flushing frequencies (no flushing or flushing every 15 or 30 days) on SDI emitter discharge and sediments within the dripline and removed in the flushing water. At the end of the season (371 h) the amount of solids carried away by the flushing water and retained in every lateral were determined as well as laboratory determination of emitter discharge for every single emitter within each dripline.*

The results indicate that increasing both flushing velocity and frequency generally resulted in improved flushing of solids. There was a greater concentration of solids in the beginning sections of the 90 m laterals, but emitter discharge tended to be slightly less at the distal ends.

Keywords. *Microirrigation, flushing, clogging, lateral.*

Introduction

Subsurface drip irrigation (SDI) systems must have good and consistent filtration, water treatment, flushing and maintenance plans to ensure long economic life (Lamm and Camp, 2007). Filtration systems do not normally remove clay and silt particles, algae and bacteria. These particles may travel through the filters as individual particles, but then flocculate or become attached to organic residues and eventually become large enough to clog emitters (Nakayama et al., 2007). Therefore, dripline flushing is needed to remove these particles and organisms that have accumulated within the driplines (Adin and Sacks, 1991; Ravina et al., 1992).

Subsurface drip systems should be designed so they can be flushed properly. To be effective, flushing must be done often enough and at an appropriate velocity to dislodge and transport the accumulated sediments (Nakayama et al., 2007). A minimum flushing velocity of 0.3 m/s is recommended for microirrigation systems (ASAE, 2003). Lamm and Camp (2007) pointed out that the ASAE criterion seems appropriate for SDI in the absence of a stronger scientific reason for greater velocities. However, some researchers have suggested a flushing velocity of 0.5 to 0.6 m/s may be needed when larger particle sizes need to be discharged, such as when coarser filters are used (Hills and Brenes, 2001; Nakayama et al., 2007).

There is not a general agreement on the best flushing frequency. Several researchers have studied different flushing frequencies: daily (Ravina et al., 1997), twice per week (Tajrishy et al., 1994), once per week (Tajrishy et al., 1994; Hills et al., 2000) or every two weeks (Ravina et al., 1997; Hills and Brenes, 2001). However, for many systems, only one flushing is carried out at the beginning or at the end of irrigation season.

The objectives of this research were to evaluate the effect of flushing velocity and flushing frequency on emitter clogging and to assess the distribution of sediments and emitter clogging in flushed and unflushed driplines.

Procedures

Experimental set-up

The study was conducted during July and August 2004 on a deep, well-drained Keith silt loam soil (fine-silty, mixed, mesic Aridic Argiustoll) at the Kansas State University Northwest Research-Extension Center, at Colby, Kansas.

The experimental set-up consisted of 27 driplines installed at a depth of approximately 75 mm with an approximate length of 90 m. The shallow installation depth was chosen for ease of dripline removal for subsequent testing at the end of the study, but did help protect the driplines from sunlight and other environmental conditions associated with surface drip irrigation (DI). The water source for the study was an unlined earthen reservoir to which groundwater could be periodically pumped for temporary storage prior to irrigation. The water was filtered to a level of 75 µm (200 mesh) with a 3 canister disk filter prior to entering the driplines. The filtration system was automatically flushed every 2 hours or at an inlet/outlet pressure differential of 49 kPa.

The dripline that was used was Netafim Typhoon 875[1], with an internal diameter (ID) of 22.2 mm and with emitters having a nominal discharge of 0.61 L/h spaced every 0.61 m. Three driplines (two black and one translucent) were installed at the same time with a tractor-mounted shank type injector in the study area on an average field slope of 0.31%.

Every dripline control head was equipped with an ABB C700 municipal-type volumetric flow accumulator (± 1.5% accuracy), a Senninger low-flow pressure regulator (0.006 to 0.504 L/s at 140 kPa), a 19 mm ID gate valve for flow adjustment, a 19 mm ball valve for quick shutoff and a pressure gauge port. Another pressure gauge port was installed at the distal end of the dripline.

Treatments

Nine treatments were tested:

1. No flushing
2. A frequency of flushing of 30 days and a flushing velocity of 0.23 m/s
3. A frequency of flushing of 30 days and a flushing velocity of 0.30 m/s
4. A frequency of flushing of 30 days and a flushing velocity of 0.46 m/s
5. A frequency of flushing of 30 days and a flushing velocity of 0.61 m/s
6. A frequency of flushing of 15 days and a flushing velocity of 0.23 m/s
7. A frequency of flushing of 15 days and a flushing velocity of 0.30 m/s
8. A frequency of flushing of 15 days and a flushing velocity of 0.46 m/s
9. A frequency of flushing of 15 days and a flushing velocity of 0.61 m/s

A plot consisted of a single dripline and each treatment was replicated three times in a randomized complete block for a total of 27 driplines. Each treatment had two plots with black driplines and a single plot with a translucent dripline. The translucent dripline was installed to allow for visual observation of the accumulated solids in the dripline at the end of the experiment. After installation with the shank-type injector, the driplines were uniformly cut to an installed length of 90.22 m. However, due to uneven stretching and shrinking during installation, dripline lengths at the time of excavation varied from 89.50 to 90.29 m with the number of emitters varying from 146 to 148 (Table 1).

The first irrigation event was initiated on July 13 and the sixteenth irrigation event was completed on August 13, 2004. No crop was planted to the study area and the area was grossly overirrigated during the summer to allow for more potential clogging and to allow for greater accumulation of solids within the driplines. The irrigation events were extended for long periods of time, but discrete events were used so that some rest periods could give time for settling of solids (Table 2). The flowrates for entire plots were measured approximately daily whenever the system was in operation. Pressure was measured at the dripline inlets and outlets at least once per irrigation event by means of a PSI-tronix pressure transducer (± 0.07 kPa accuracy). The average head loss during normal irrigation in the driplines was 0.21 kPa, once the dripline inlet and outlet height differences were considered. Every dripline flowrate was checked periodically during the irrigation season and was adjusted as needed with the gate valve to the nominal level of 90.95 L/h.

Irrigation water at the plot inlet was sampled periodically during selected irrigation events to determine the total suspended solids (TSS) and water temperature. TSS were determined in the laboratory by filtering a sample through a previously weighed 2 μm Whatman filter paper and drying the residue retained on the paper and the paper to a constant weight at 103 to 105°C. Temperature was measured with a liquid thermometer (± 0.1°C precision). The average value of TSS for the periodic sampling was 19.2 mg/L, with a minimum of 3.9 mg/L for the first irrigation event and a maximum of 41.9 mg/L for the last irrigation event (Figure 1). The cumulative amount of TSS applied through each dripline was estimated from linear interpolation of the TSS values on selected dates and multiplying those values by the total amount of applied water and was calculated to be approximately 6.9 kg for each dripline. The mean of the water temperature was 21.7°C, with a maximum of 26.7°C on July 14 and a minimum of 18.4°C on August 13. The differences in water temperature are not only related to climatic conditions but also related to the residence time of the pumped groundwater in the surface reservoir. The pumped groundwater enters the reservoir at approximately 15°C.

Table 1. Flushing frequency and flushing velocity treatments, plot number, dripline length and number of emitters.

Number of flushings	Target flushing velocity (m/s)	Plot No.	Length (m)	Number of emitters
None	-	9	89.63	147
		16	90.23	147
		20	89.59	146
One at 30 days	0.23	7	90.23	147
		18	89.52	146
		25	90.24	148
	0.30	6	90.12	146
		10	90.18	148
		23	90.13	148
	0.46	2	89.68	146
		17	89.55	147
		24	90.29	148
	0.61	1	89.23	147
		11	89.88	147
		27	89.97	148
Two at 15 and 30 days	0.23	8	89.89	147
		15	89.71	146
		19	90.34	148
	0.30	3	89.50	146
		14	89.93	147
		22	89.92	147
	0.46	4	90.28	147
		12	89.61	147
		26	89.62	148
	0.61	5	90.07	147
		13	90.02	147
		21	89.64	147

Table 2. Characteristics of the sixteen irrigation events.

Irrigation Event	Dates	Event time (h)	Cumulative time (h)	Approximate cumulative volume (m^3)*
1	July 13	4.00	4.00	0.49
2	July 14 to 15	24.50	28.50	2.76
3	July 15 to 16	14.25	42.75	5.59
4	July 18 to 19	24.25	67.00	7.92
5	July 20 to 21	23.25	90.25	10.13
6	July 21 to 22	14.75	105.00	11.39
7	July 22 to 24	45.40	150.40	16.22
8	July 25 to 26	13.15	163.55	17.46
9	July 26 to 27	20.75	184.30	18.11
10	July 28 to 31	72.75	257.05	24.54
11	August 3 to 5	35.10	292.15	29.28
12	August 6 to 8	49.00	341.15	33.00
13	August 9 to 10	18.60	359.75	34.81
14	August 11	2.00	361.75	35.10
15	August 12	8.00	369.75	36.22
16	August 13	2.00	371.75	36.22

* The irrigation volumes at the end of each event are approximate since the events were based on actual times and estimated dripline flowrates. Short term adjustment events were conducted periodically over the course of the experiment to equalize total accumulated irrigation volumes. Event time adjustments to allow for identical accumulated flow amounts were conducted on July 27 and August 13.

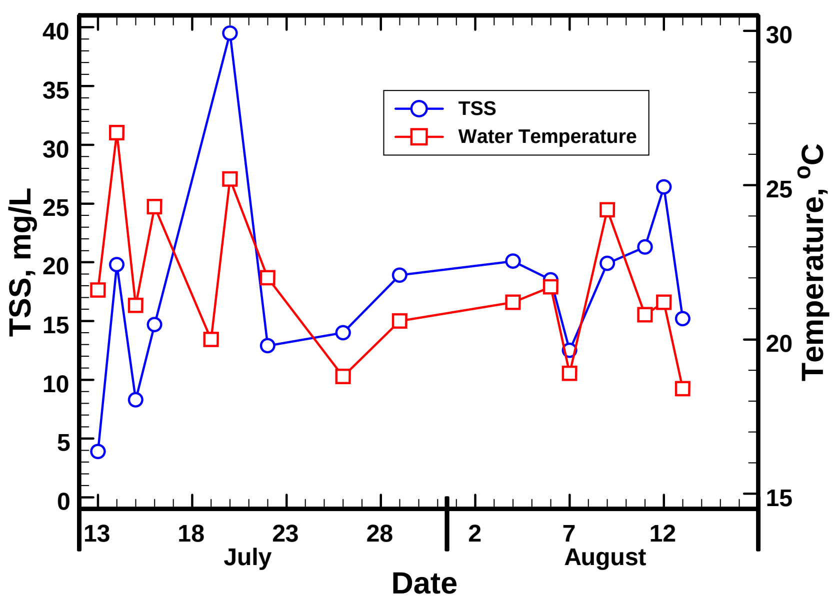

Figure 1. Time series of irrigation water total suspended solids (TSS) and temperature.

Flushing procedure

The first flushing event was conducted when an amount of 18.1 m^3 had been applied through each dripline on July 27 and 28. The second flushing event was performed on August 16 and 17 after a total of 36.2 m^3 of water had been applied through each dripline. During the flushing events, the gate valve at the control head was carefully adjusted to allow the required treatment flushing velocity. The adjustment was made by raising the flowrate slowly over the course of approximately 3 to 5 minutes to avoid exceeding the required treatment flow velocity. However, even with this technique actual flushing velocities slightly exceeded the targeted velocities (Table 3). The duration of the entire flushing event including the adjustment time was held constant at 15 minutes. The average friction head loss during flushing as measured by the pressure transducer was approximately 9, 13, 23, and 39 kPa with the target flushing velocities of 0.23 m/s, 0.30 m/s, 0.46 m/s and 0.61 m/s, respectively.

A removable 1-m standpipe and flush valve apparatus was added to the distal end of the dripline before the flushing event to simulate a possible elevation head that might be associated with flushing a subsurface dripline. All of the water from a single dripline flushing event was collected in a 230 L tank. The total flushing water volume was filtered through a Culligan household water filter with a filtration level of 5 µm in order to retain most of the suspended solids. The volume of flushing water collected in the tank was estimated by subtracting the estimated emitter discharge amount during flushing from the applied flushing water volume (Table 3). This estimate was thought to be much more accurate than using volumetric markings on the collection tank.

Table 3. Flushing and flowrate characteristics (means ± standard deviations) during the various dripline flushing events.

Flushing event	No. of total flushings	Target Flushing velocity m/s	Actual Flushing velocity m/s	Applied flushing water volume (L)	Estimated volume of flushing water collected in tank (L)	Dripline flowrate during event (m^3/h)
August 16-17	1	0.23	0.28	97 ± 5	88 ± 5	0.39 ± 0.02
		0.30	0.36	124 ± 2	113 ± 2	0.50 ± 0.01
		0.46	0.53	184 ± 4	171 ± 4	0.73 ± 0.01
		0.61	0.68	247 ± 4	231 ± 5	0.96 ± 0.06
July 27 to 28	2	0.23	0.28	98 ± 6	88 ± 6	0.39 ± 0.02
		0.30	0.35	124 ± 5	113 ± 5	0.49 ± 0.02
		0.46	0.51	179 ± 5	166 ± 5	0.71 ± 0.02
		0.61	0.68	239 ± 5	224 ± 4	0.95 ± 0.02
August 16 to 17		0.23	0.27	96 ± 5	86 ± 5	0.38 ± 0.02
		0.30	0.35	122 ± 7	112 ± 7	0.49 ± 0.03
		0.46	0.51	179 ± 0	167 ± 0	0.72 ± 0.00
		0.61	0.69	240 ± 3	225 ± 3	0.96 ± 0.01

Determination of the amount of solids in each dripline

After the second flushing event, 10 control lengths of each dripline were established. The lengths were measured from the distal end to the inlet of each lateral (i.e., section 1 at inlet and section 10 at distal end of dripline). Thus, there were 9 sections (section 2 to 10) of approximately 9.14 m and 1 (section 1) of 7.92 m. The longer sections 2 through 10 generally had 15 emitters for testing while the shorter section 1 had approximately 13 emitters. Each section (control length) was established by exposing the dripline at the appropriate location and pinching it off with binder clamps. The sections were then carefully excavated and hauled on a 9.5 m flat bed trailer to the laboratory for emitter discharge tests. Each section was manually cleaned externally with a pressurized hose to remove excess soil and debris. After external cleaning each section was placed on a sloping (10%) platform where the clamps were removed and the trapped dirty water was allowed to drain into a 3 L rectangular container. Then, a short 1 s burst of pressurized (approximately 140 kPa) water (approximately 2 L) was pumped through to dislodge additional loose sediments within the dripline. This water was also collected in the same container. The container was dried until a constant weight was reached and then the amount of remaining solids was determined. This technique was used to provide an estimate of the amount of solids in each dripline but would not be able to account for any solids that failed to dislodge during the process.

Emitter discharge tests

After the driplines were excavated, the discharge for each emitter in all ten dripline sections of each plot was measured in the laboratory. The laboratory set-up allowed testing of six sections at the same time. Each of the six dripline sections was attached to a common inlet and outlet manifold system where driplines were suspended on a support rack made of 25 mm ID PVC pipe. Emitters from each drip lateral were aligned so that a collection cup rack could be used to simultaneously collect emitter discharge for the 6 driplines. Small cotton strings (kite string) attached to the dripline at each emitter extended approximately 70 mm below the dripline, were saturated during the conditioning periods, and then wicked water into the collection cups during an 18 min period. The fresh water used in these tests was pumped and recirculated from a 320 L tank that was filtered with an API 38 mm spin clean Y-filter with a 75 µm (200 mesh) screen. Periodically fresh water was added to the tank to replace water lost in the testing process and to maintain water temperature in an acceptable range (23 to 31°C). The water temperature was recorded to correct the water volume from the weight measurements. To account for the variation due to minor fluctuations in pressures from test to test, the calculated emitter discharges were normalized to the design pressure using the emitter exponent for that dripline type. The emitter discharge collection facility and the procedures used to evaluate emitter discharge in this study were adapted from facilities and procedures described by Clark et al. (2005).

Emitter discharge function

Laboratory tests were performed on both new black and translucent driplines to determine the emitter discharge function coefficient and exponent. The procedure was similar to the procedures for testing the emitter discharge from the SDI driplines. The emitter discharge was measured under 6 different pressures (43.3, 53.0, 64.4, 65.6, 83.7, and 100.7 kPa). Discharge was measured for 30 emitters from each of the black (2) and translucent (1) rolls used in the field SDI installation.

The emitter discharge function obtained from the experimental data was:

$$q = 0.0885 \cdot P^{0.4737} \qquad R^2 = 0.96;\ N = 540;\ V_m = 2.56\%$$

where q is emitter discharge in L/h, P is pressure in kPa, N is the number of emitters and V_m is the manufacturing coefficient of variation, calculated as:

$$V_m = \frac{S_{qe}}{\bar{q}} \cdot 100$$

where S_{qe} is the standard deviation of emitter discharge and $\bar{q}$ is the average emitter discharge. Evaluating the emitter discharge function at a nominal design pressure of 68.9 kPa indicated that the emitter discharge is 7.7% (q=0.657 instead of 0.61 L/h) greater than the manufacturer's specification.

Statistical treatment

Statistical analyses were conducted using the Proc GLM (general linear models) procedure of the SAS statistical package (SAS Institute, Cary, NC, USA) at a significance level of P=0.05. Total solids in the flushing water were analyzed with respect to both flushing velocity and frequency. When analyzing the dripline solids amount and emitter discharge for the various dripline sections, the model included as fixed effects the treatment (frequency of flushing and velocity), the section and the interaction between them, when the interaction was significant. Tukey's test was used, at the P=0.05 level to separate the means.

Results and Discussion

Solids in the flushing water

The amount of total solids in the flushing water as measured by deposition on the filter cartridges (Table 4) was significantly greater in the driplines flushed only once with a flushing velocity of 0.61 m/s than in those flushed once or twice with a flushing velocity of 0.23 m/s and those flushed twice with a flushing velocity of 0.30 m/s. There was a tendency that the greater the flushing velocity, the greater the amount of solids in the flushing water. Only the flushing velocity had a significant effect on the results with neither the flushing frequency nor the interaction of frequency and velocity significantly affecting the amount of total solids retained on the filter cartridges. However, the variability of the results with large standard deviations should be noted. There were no significant differences among flushing velocities for the August 16-17 flushing for the treatments that received two flushings, but for the July 27-28 flushing and for the single flushing treatment of August 16-17, there were significantly greater solids deposition on the cartridge for the 0.61 target flushing velocity.

Table 4. Total solids (g) in the flushing water as measured in the water filter cartridges (mean values ± standard deviations) as affected by the number of flushings and flushing velocity.

No. of total flushings	Flushing event	Target flushing velocity (m/s)			
		0.23	0.30	0.46	0.61
2	July 27-28	0.56 ± 0.2 [b]	0.9 ± 0.9 [b]	1.3 ± 0.6 [b]	4.0 ± 1.7 [a]
	August 16-17	14.5 ± 2.8 [a]	15.2 ± 3.7 [a]	17.2 ± 0.7 [a]	17.1 ± 1.9 [a]
	Total of both	15.0 ± 1.76 [B]	16.1 ± 2.6 [B]	18.5 ± 0.4 [AB]	21.1± 1.8 [AB]
1	August 16-17	12.9 ± 3.1 [B b]	16.8 ± 4.4 [AB b]	16.9 ± 1.0 [AB b]	27.0 ± 6.0 [A a]

Different upper case letters indicate significant differences (P < 0.05) between values for each flushing frequency. Different lower case letters indicate significant differences (P < 0.05) between flushing velocities for each flushing event

Solids within the driplines

At the conclusion of the field study, the amount of solids in each of the 10 dripline sections for each single dripline replication for each flushing treatment was determined through the drainage and short-burst pressurized water cleaning procedure discussed in the Procedures. There was a statistical interaction between dripline section and flushing treatment for the amount of solids within the dripline. Thus, the effects of section and treatment cannot be considered independently.

As might be expected, the maximum amount of solids for both the overall dripline and each individual section occurred in the driplines that were not flushed during the study (Table 5 and Figure 3). For the most of the dripline sections, no differences were observed in the amount of solids contents with regard to flushing velocity and the flushing frequency. Only in section number 3 (17.1 to 29.3 m from dripline inlet) was the amount of dripline solids significantly greater for the smaller flushing velocities and frequencies (i.e., 0.23 m/s and 0.30 m/s with one flushing and also 0.23 m/s with two flushings when compared with 0.61 m/s with one flushing). The amount of solids was also greatest with Section 3 for the treatment that was not flushed This section may have the greatest solids because of greater deposition there during the normal irrigation events as flow velocity decreases along the dripline to a threshold level. The flow velocity at the midpoint of Section 3 can be estimated to be approximately 0.05 m/s during normal irrigation events (assuming an approximate nominal emitter discharge along the dripline) which would be an approximately 25% velocity reduction from the inlet. These results concerning the location of solids deposition do not agree with those obtained by Shannon et al. (1982), who in 122-m driplines, found that the sediment deposition began at about 61 m and increased steadily until about 110 m, then decreased in the last 10 m.

As flushing velocity increased, there was a tendency for greater solids removal and/or more equal distribution within the dripline (Figure 3). Flushing frequency had a less consistent effect on solids removal and distribution with the single flushing event sometimes being better than the two flushing events (Table 5). It is possible that when sediments are allowed to accumulate and conglomerate over a longer time period that these aggregates might have some dragging effect on other sediments during flushing and, thus, the solids removal might be greater. Additionally, greater deposition over a longer time period between flushing events would have decreased the cross sectional area of the dripline which would then increase the localized flushing velocity at that point for a given overall dripline flowrate. Results obtained by Shannon et al. (1982)

indicate that the sediments can move similar to sand dunes with building of deposits followed by erosion of the highest margins exposed to greater flow velocities and then the process starts again further along the dripline. These overall results suggest that longer flushing duration would be required to further reduce the amount of sediments remaining in the driplines.

Table 5. Average ± standard deviation of solids (g) loosely retained in the driplines after the flushing events as related to dripline section and flushing treatment. Section 1 is at the inlet and section 10 is at the distal end.

Section	Number of flushings								
	0	1				2			
	Target flushing velocity (m/s)								
	0	0.23	0.30	0.46	0.61	0.23	0.30	0.46	0.61
1	4.47 ± 0.14 $^{a\ A}$	1.51 ± 0.94 ^{b}	1.27 ± 0.23 $^{b\ AB}$	1.11 ± 0.60 ^{b}	1.08 ± 0.70 ^{b}	1.26 ± 0.39 ^{b}	1.53 ± 0.74 ^{b}	1.15 ± 0.76 ^{b}	0.93 ± 0.37 ^{b}
2	4.79 ± 0.69 $^{a\ A}$	1.83 ± 0.93 ^{b}	1.62 ± 0.37 $^{b\ AB}$	1.39 ± 0.45 ^{b}	0.78 ± 0.54 ^{b}	1.71 ± 0.48 ^{b}	1.50 ± 0.15 ^{b}	1.25 ± 0.49 ^{b}	1.17 ± 0.29 ^{b}
3	4.93 ± 0.08 $^{a\ A}$	1.86 ± 0.20 ^{b}	1.89 ± 0.26 $^{b\ A}$	1.15 ± 0.06 ^{cd}	0.91 ± 0.21 ^{d}	1.65 ± 0.40 ^{bc}	1.59 ± 0.18 ^{bcd}	1.28 ± 0.33 ^{bcd}	1.33 ± 0.30 ^{bcd}
4	3.88 ± 0.55 $^{a\ AB}$	1.63 ± 0.20 ^{b}	1.46 ± 0.13 $^{b\ AB}$	1.18 ± 0.22 ^{b}	0.76 ± 0.47 ^{b}	1.47 ± 0.09 ^{b}	1.24 ± 0.26 ^{b}	1.06 ± 0.27 ^{b}	1.18 ± 0.53 ^{b}
5	3.29 ± 0.61 $^{a\ BC}$	1.63 ± 0.22 ^{b}	1.55 ± 0.30 $^{b\ AB}$	1.00 ± 0.18 ^{b}	0.92 ± 0.43 ^{b}	0.95 ± 0.04 ^{b}	1.23 ± 0.23 ^{b}	1.28 ± 0.36 ^{b}	1.04 ± 0.16 ^{b}
6	3.10 ± 0.17 $^{a\ BCD}$	1.27 ± 0.25 ^{b}	1.25 ± 0.39 $^{b\ AB}$	1.10 ± 0.19 ^{b}	0.80 ± 0.38 ^{b}	1.09 ± 0.36 ^{b}	1.27 ± 0.27 ^{b}	1.12 ± 0.42 ^{b}	1.29 ± 0.15 ^{b}
7	3.02 ± 0.11 $^{a\ BCD}$	1.14 ± 0.19 ^{b}	1.30 ± 0.10 $^{b\ AB}$	1.04 ± 0.18 ^{b}	0.97 ± 0.30 ^{b}	1.23 ± 0.28 ^{b}	1.13 ± 0.27 ^{b}	1.12 ± 0.50 ^{b}	1.73 ± 0.59 ^{b}
8	2.43 ± 0.56 $^{a\ CD}$	0.98 ± 0.19 ^{b}	1.03 ± 0.25 $^{b\ B}$	0.90 ± 0.18 ^{b}	0.89 ± 0.20 ^{b}	0.99 ± 0.15 ^{b}	0.98 ± 0.23 ^{b}	1.23 ± 0.45 ^{b}	1.32 ± 0.18 ^{b}
9	2.07 ± 0.08 $^{a\ D}$	1.12 ± 0.35 ^{b}	1.02 ± 0.09 $^{b\ B}$	0.94 ± 0.39 ^{b}	0.80 ± 0.48 ^{b}	0.95 ± 0.12 ^{b}	0.85 ± 0.05 ^{b}	1.17 ± 0.19 ^{b}	1.30 ± 0.22 ^{b}
10	2.38 ± 0.07 $^{a\ CD}$	1.05 ± 0.12 ^{b}	1.13 ± 0.10 $^{b\ B}$	1.12 ± 0.14 ^{b}	1.01 ± 0.29 ^{b}	1.15 ± 0.37 ^{b}	1.53 ± 0.27 ^{b}	1.26 ± 0.57 ^{b}	1.54 ± 0.18 ^{b}
Overall dripline	34.4 ± 1.86 ^{a}	14.1 ± 2.74 ^{b}	13.6 ± 0.19 ^{b}	11.0 ± 1.90 ^{b}	8.95 ± 3.86 ^{b}	12.5 ± 2.10 ^{b}	12.9 ± 2.03 ^{b}	12.0 ± 3.97 ^{b}	12.9 ± 1.29 ^{b}

Within each section and overall dripline, different lowercase letters indicate significant differences ($P < 0.05$) among flushing treatments (the rows of the table). Within each flushing treatment, different uppercase letters indicate significant differences ($P < 0.05$) among dripline sections (the columns of the table).

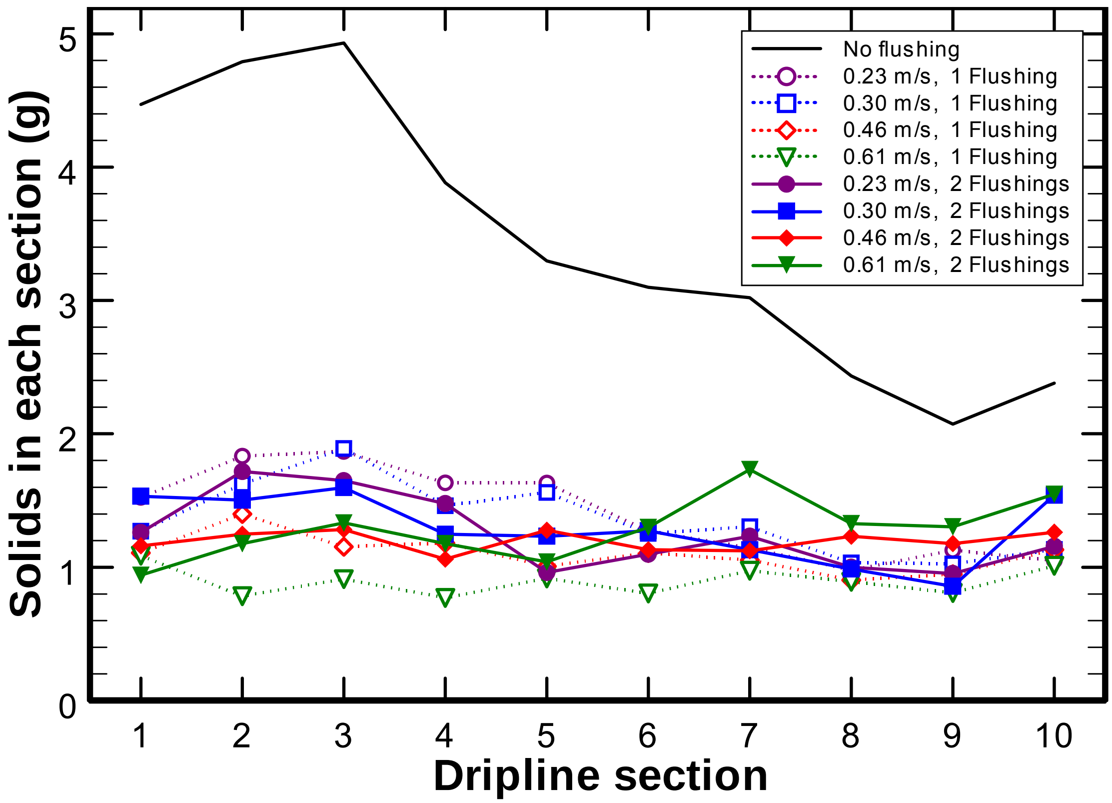

Figure 3. Solids recovered from each dripline section and flushing treatment at the end of the field study. Section 1 is at the inlet and section 10 is at the distal end.

Emitter discharge

The average emitter discharge at the conclusion of the field experiment was measured in the laboratory and the discharge value was normalized to the nominal pressure (68.9 kPa). Although data from each and every emitter is available it is impractical to observe emitter-by-emitter differences along the length of the dripline graphically for all flushing treatments in a single graph because of the range of possible discharges (i.e., fully clogged to 100% discharge). Thus, a reasonable compromise was to depict trends in the average emitter discharge within a dripline section (Figure 4). Most of the emitter discharges were within 5% of the new, unused emitter average discharge of 0.657 L/h at a pressure of 68.9 kPa that were measured in the laboratory (Figure 4 and Table 6). The average emitter discharge for a total of 3970 emitters from the field study was 0.64 L/h which is approximately 2.5% lower than the discharge for the new, unused emitters. There were only 6 emitters that were nearly or fully clogged (i.e., 0 to 5% of discharge of new and unused emitters).

There was no statistically significant interaction between flushing treatment and dripline section, so it is legitimate to discuss these effects separately. Least square means and their associated standard error were computed for the different flushing treatments and also for the different dripline sections (Figures 5 and 6). Least square means are depicted here because of more statistical accuracy in means separation when there are differences in sample size. However in this case there were only very minor differences in sample size and each treatment sample size was approximately 440 emitters, so there is very little difference between the least square means and the simple mathematical means of the treatments (Table 7).

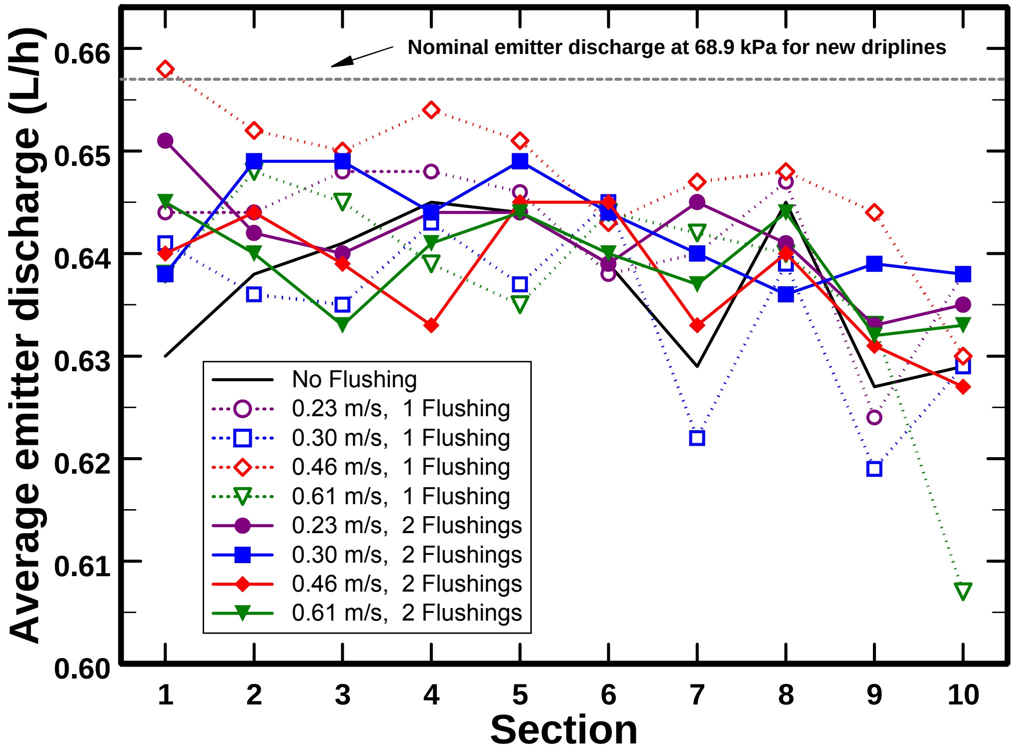

Figure 4. Average emitter discharge for each dripline section as affected by flushing velocity and the number of flushings. Section 1 is at the inlet and section 10 is at the distal end. Note: The average emitter discharge for the dripline sections only vary by less than 8%.

Table 6. Percentage of SDI emitters from the field study having a specified fraction of the discharge of new, unused emitters for the various flushing frequency and flushing velocity treatments.

Fraction of new emitter discharge	Number of flushings								
	0	1				2			
	Target flushing velocity (m/s)								
	0	0.23	0.30	0.46	0.61	0.23	0.30	0.46	0.61
1.1-1.2	0.2	-	-	-	-	-	-	-	-
1.0-1.1	27.0	26.8	32.5	24.7	30.2	30.8	21.7	40.1	31.9
0.9-1.0	66.6	70.5	62.7	69.9	65.1	65.1	73.5	56.0	62.4
0.8-0.9	5.2	2.0	4.5	4.3	3.6	3.2	3.4	3.9	4.1
0.7-0.8	0.5	0.2	0.2	0.9	0.5	0.5	0.7	-	0.2
0.6-0.7	0.2	0.2	-	-	-	0.2	-	-	0.7
0.5-0.6	-	-	-	-	-	-	-	-	0.0
0.4-0.5	-	-	-	0.2	0.5	-	-	-	0.2
0.3-0.4	-	0.2	-	-	-	-	-	-	-
0.2-0.3	-	-	-	-	-	-	-	-	-
0.1-0.2	-	-	-	-	-	-	0.2	-	-
0.0-0.1	0.2	-	-	-	0.2	-	0.5	-	0.5

There was a statistically significant difference (P<0.05) in emitter discharge from the SDI emitters with the single flushing treatment with target flushing velocity of 0.46 m/s being significantly greater than when flushing twice at 0.46 m/s and 0.61 m/s, flushing once at 0.30 m/s and 0.61 m/s, and without flushing (Figure 5 and Table 7). However, the numerical differences between the treatments are quite small and may have little practical consequence. These numerical and statistical differences are not explained logically from the treatment structure and do not appear consistent with typical hypotheses that increased flushing frequency and increased flushing velocity will help prevent emitter clogging and thus retain greater emitter discharges. The results may be reflecting that improvements in emitter design and manufacturing and improved filtration systems may be reducing some of the clogging potential for SDI emitters (Camp et al., 2000). Additionally, the emitters used in this study were the integral type, short flow-path, welded-on emitters that some researchers have stated that typically have better performance with sediment-laden water (Adin and Sacks, 1991, Hills and Brenes, 2001, Trooien and Hills, 2007). It should be restated that it is estimated that nearly 7 kg of TSS flowed through each dripline (approximately 90 m) during the course of the field experiment, so this was an appreciable sediment load to contend with. Additionally, there were also some statistically significant differences in flushing treatment on solids deposition within the dripline. The small reductions in emitter discharge and the small amount of severely clogged emitters in this study does not mean that dripline flushing is not important.

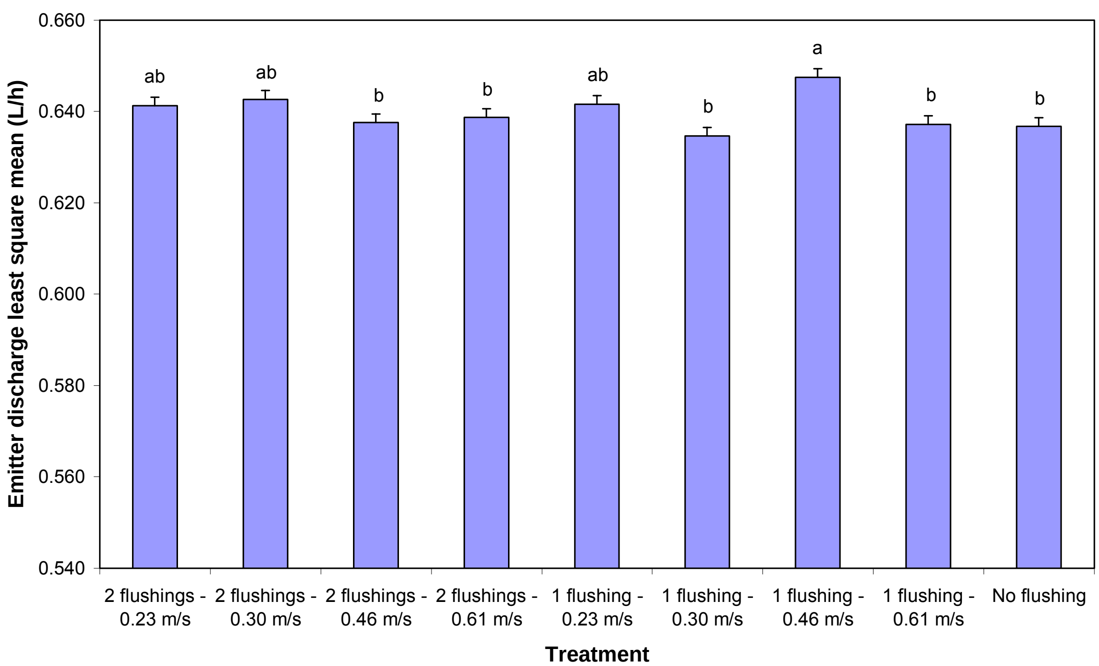

Figure 5. Discharge from the SDI emitters (least square mean ± standard error) as affected by flushing frequency and flushing velocity. Different lowercase letters above each column indicate significant differences at P<0.05. This data is averaged across all dripline sections to represent the overall effect on the dripline of flushing treatment.

Table 7. Emitter discharge (L/h) for the SDI emitters (average ± standard deviation) as measured in the laboratory at the end of the field experiment for every flushing treatment and dripline section.

Section	Number of flushings									All flushing treatments
	0	1				2				
	Target flushing velocity (m/s)									
	0	0.23	0.30	0.46	0.61	0.23	0.30	0.46	0.61	
1	0.63 ± 0.04^{b}	0.64 ± 0.02$^{ab\ A}$	0.64 ± 0.03^{a}	0.66 ± 0.02$^{ab\ A}$	0.64 ± 0.03$^{ab\ AB}$	0.65 ± 0.02^{ab}	0.64 ± 0.03^{ab}	0.64 ± 0.02^{ab}	0.65 ± 0.06^{ab}	0.64 ± 0.03†
2	0.64 ± 0.04	0.64 ± 0.02^{A}	0.64 ± 0.03	0.65 ± 0.02^{A}	0.65 ± 0.03^{A}	0.64 ± 0.02	0.65 ± 0.02	0.64 ± 0.02	0.64 ± 0.06	0.64 ± 0.03†
3	0.64 ± 0.03	0.65 ± 0.02^{A}	0.64 ± 0.02	0.65 ± 0.03^{A}	0.65 ± 0.03^{A}	0.64 ± 0.02	0.65 ± 0.02	0.64 ± 0.03	0.63 ± 0.09	0.64 ± 0.04†
4	0.65 ± 0.03	0.65 ± 0.02^{A}	0.64 ± 0.02	0.65 ± 0.02^{A}	0.64 ± 0.05^{AB}	0.64 ± 0.02	0.64 ± 0.03	0.63 ± 0.06	0.64 ± 0.02	0.64 ± 0.03†
5	0.64 ± 0.02	0.65 ± 0.03^{A}	0.64 ± 0.08	0.65 ± 0.02^{A}	0.64 ± 0.10^{AB}	0.64 ± 0.02	0.65 ± 0.02	0.65 ± 0.02	0.64 ± 0.02	0.64 ± 0.05†
6	0.64 ± 0.02	0.64 ± 0.04^{AB}	0.65 ± 0.03	0.64 ± 0.03^{AB}	0.64 ± 0.02^{A}	0.64 ± 0.03	0.64 ± 0.03	0.65 ± 0.02	0.64 ± 0.03	0.64 ± 0.03†
7	0.63 ± 0.10	0.64 ± 0.03^{AB}	0.62 ± 0.10	0.65 ± 0.03^{AB}	0.64 ± 0.03^{AB}	0.65 ± 0.03	0.64 ± 0.03	0.63 ± 0.03	0.64 ± 0.04	0.64 ± 0.05$^{\dagger\Omega}$
8	0.65 ± 0.02	0.65 ± 0.02^{A}	0.64 ± 0.03	0.65 ± 0.03^{AB}	0.64 ± 0.03^{AB}	0.64 ± 0.02	0.64 ± 0.03	0.64 ± 0.03	0.64 ± 0.03	0.64 ± 0.03†
9	0.63 ± 0.02	0.62 ± 0.03^{B}	0.62 ± 0.10	0.64 ± 0.03^{AB}	0.63 ± 0.06^{AB}	0.63 ± 0.06	0.64 ± 0.03	0.63 ± 0.02	0.63 ± 0.03	0.63 ± 0.05$^{\Omega}$
10	0.63 ± 0.03^{ab}	0.64 ± 0.03$^{a\ AB}$	0.63 ± 0.03^{ab}	0.63 ± 0.03$^{ab\ B}$	0.61 ± 0.10$^{b\ B}$	0.64 ± 0.03^{ab}	0.64 ± 0.03^{a}	0.64 ± 0.04^{ab}	0.63 ± 0.03^{ab}	0.63 ± 0.04$^{\Omega}$
Overall dripline	0.64 ± 0.04^{b}	0.64 ± 0.03^{ab}	0.63 ± 0.05^{b}	0.65 ± 0.03^{a}	0.63 ± 0.06^{b}	0.64 ± 0.03^{ab}	0.64 ± 0.03^{ab}	0.64 ± 0.03^{b}	0.64 ± 0.05^{b}	--

Within each section and overall dripline, different small letters show significant differences among flushing treatments. Within each flushing treatment, different capital letters show significant differences among dripline sections ($P < 0.05$).

The statistical analysis with regard to distance along the dripline (i.e., dripline section) indicates that the discharge of emitters from sections 1 to 6 (0 to 53.6 m) and 8 (62.8 to 71.9 m) was significantly greater (Figure 6 and Table 7) than the discharge of the emitters of section 9 and 10 (from 71.9 to 90.2 m). These results agree with the results of other research (Shannon et al., 1982; Ravina et al., 1992) which indicated increased clogging and sediment deposition in the distal sections.

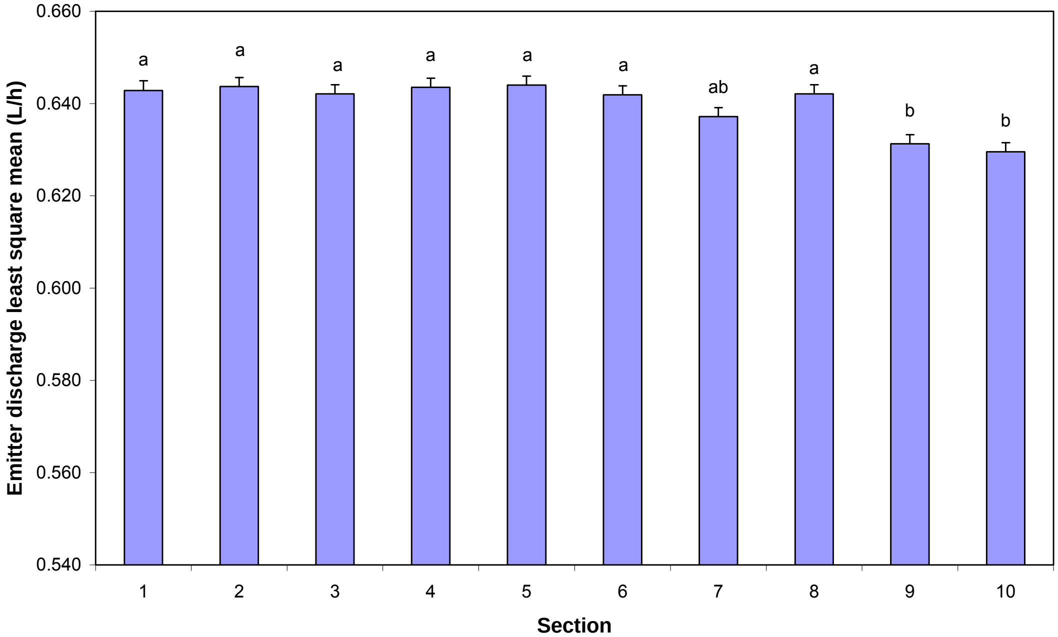

Figure 6. Discharge from the SDI emitters (least square mean ± standard error) as affected by section of the dripline (Section 1 is the inlet and Section 10 is the distal end). Different lowercase letters above each column indicate significant differences at $P<0.05$. This data is averaged across all flushing treatments to indicate the effect of location within the dripline on emitter clogging.

Conclusions

Flushing of driplines continues to be an important aspect in maintaining good performance and ensuring longevity of SDI systems. Sediment deposition within the SDI dripline was significantly greater when no flushing was performed during the course of the experiment and was nearly 3 times greater than for those driplines that were flushed. Sediment deposition within the nonflushed dripline was actually greatest nearer the inlet reaching a maximum at about 1/3 of the distance along the dripline which suggests settling of particles in laminar flow within the dripline and also possibly increased adhesion and conglomeration as additional sediments past through these inlet sections. There were significantly greater total sediments in the flushwater from the driplines that had a single flushing and a flushing velocity of 0.61 m/s as compared to the smallest flushing velocity (0.23 m/s) treatments which indicates that greater flushing velocities will remove more solids from the driplines as would be anticipated. The pattern of sediment deposition within the flushed driplines was different than for the non-flushed driplines. There was sometimes greater deposition near the inlets for these flushed driplines, particularly with smaller flushing velocities and greater solids deposition closer to the distal ends when flushing velocity was greater. These differences suggest that the flushing events were not of sufficient duration to move the sediments completely from the dripline. The sediment deposition and movement appear to follow known theory about deposits moving in a sand dune fashion within the pipe.

There was a less consistent effect of flushing frequency on sediment removal from the dripline as measured in the flushing water and on the amount and location of sediments remaining in the driplines. There was numerically greater sediment removal for a single flushing at the greatest flushing velocity but as flushing velocity decreased there tended to be slightly better sediment removal with more frequent flushing. A greater solids deposition with the less frequent flushing conceivably may have resulted in an increased localized flushing velocity at the point of deposition causing more erosion of the deposition and thus greater removal by the flushing water. Another possibility may be increased aggregate size with less frequent flushing may have had a dragging effect on the deposits thus carrying more in the flushing water.

Although not a factor in this study, increasing the duration of flushing may be a more important and also less expensive means (i.e., increased flushing events increases labor and greater flushing velocities can greatly increase SDI system costs through different pumping requirements and reduced zone size leading to needing more pipes, controls and connectors) of increasing the overall effectiveness of flushing given the manner in which sediments move within the dripline during flushing. The effect of flushing duration should be examined more closely in field and laboratory studies and perhaps through computational fluid dynamics (CFD).

Flushing frequency and flushing velocity did not have great effects on the resulting SDI emitter discharges measured at the end of the experiment. The average emitter discharge (all flushing treatments and emitter locations within the field) at the conclusion of the study was only 2.5% lower than the discharge for new and unused driplines. This suggests that improvements in emitter designs and filtration that have occurred over time have reduced but not eliminated SDI emitter clogging concerns.

Acknowledgements

[1] Mention of tradenames is for informational purposes only and does not constitute endorsement by the authors or by the institutions they serve.

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