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Research Paper

Effectiveness of Emitter Flushing used for Subsurface Drip Irrigation System

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ABSTRACT

Filtration plays vital role to improve the efficacy and reduce the maintenance of drip irrigation systems. The experiment was conducted to evaluate drip irrigation filters (gravel, disk filter and their combination) for groundwater filtration. Water quality parameters responsible for emitter plugging, such as total solids, turbidity, Ca, Mg, CO_3 and HCO_3 were analyzed at the entry and exit points of filters. The filtration efficiency for water quality parameters was estimated with individual filters and in combination. Significant improvement was observed for turbidity, total solids, carbonate and bicarbonate. The filtration efficiency with combination filter was 14.3±8.8% for turbidity and 16.3±9.31% for bicarbonates. Gravel filter gave better results for filtration of bicarbonate in comparison to the disk filter. Emitters protected by the gravel media filter experienced the largest flow rate reductions but emitters protected by combination filters experienced least flow rate reduction. Backwashing of filters reduces the filtration efficiency and head loss. To reduce emitter plugging by removal of accumulated sediment, flushing of mains, submains and laterals are recommended. Higher improvement in uniformity coefficient was observed in subsurface drip after flushing operation. The results may be utilized in planning and design of subsurface drip irrigation system to diminish emitter clogging incidence.

Keywords: Clogging; Filtration; Emission Uniformity; Lateral placement; Filter.

INTRODUCTION

Indian agriculture is facing increased competition for water resources, and reduction in agricultural water availability. The main reason for such issue is increased water demand in domestic, industrial and other sectors in recent years. There is urgent need to utilize water efficiently and improve water productivity in agricultural sector. In this regard, localized irrigation systems can be effective and efficient solutions to overcome this challenging task without sacrificing the agricultural productivity. However, continuous discharge of water through small and narrow path of emitter restricts the expansion of micro irrigation systems in the country as it is highly susceptible to clogging by impurities present in water. If the water is not properly filtered and the irrigation system not properly maintained, it can result in emitter clogging. (Capra and Scicolone, 2001; Keller and Bliesner, 1990; Pitts et al. 1990). The obstruction of emitters affects the hydraulic performance of the irrigation system, reducing the uniformity of waterdistribution, increasing the operating costs and the investment risks, and discouraging farmers from employing micro irrigation technology. To minimize the limitations of this system, it is recommended to provide suitable water filtration systems to remove the impurities (e.g., physical, chemical, or both simultaneously) present in the irrigation water.

One approach that stands out among the various physical processes available for removing the impurities from irrigation water is the sand filter. This filter performs better than either the screen or disc filter due to its superior retention of organic particles and algae (Capra and Scicolone, 2004; Bernardo et al. 2005). However, the hydraulic performance of irrigation systems can be affected by the operation dynamics of sand filters. The continued obstruction of media pores by water contaminants increases the system head loss and alters the total dynamic head of the pump, with consequent changes in the working pressure and system flow. In drip irrigation system, quality of irrigation water, filtration system and emitter play a vital role. Water treatment through filtration is a key to reduce emitter clogging. Although an adequate filtration system can control emitter clogging (Nakayama and Bucks, 1990; Oron et al. 1979), yet clogging cannot be avoided completely (Tajrishy et al. 1994).The type of particles in irrigation water depends on the source (Adin and Elimelech, 1989; Adin et al. 1989; Tiehma et al. 1999). The factors, that influence whether a particle is retained by a filter, include size, shape, surface load, settling velocity. Since these factors vary from one type of particle to another, the particle size distribution, the variety of shapes and the density intervals must also be considered (Lawler, 1997). Extent of emitter clogging was studied by many researchers in details (Bucks et al., 1979; Capra and Scicolone, 2007; Puig-Bargues et al., 2005; Taylor et al., 1995; Tripathi et al., 2016).

The emitter clogging can be classified into three types: physical clogging, chemical clogging and biological clogging (Bucks et al., 1979). Physical clogging is caused by suspended inorganic particles (such as sand, silt and clay), organic materials (animal residues, snails, etc.), and microbiological debris (algae, protozoa, etc.); physical materials are often combined with bacterial slimes. Chemical clogging problems are due to dissolved solids interacting with each other to form precipitates, such as the precipitation of calcium carbonate in waters having calcium and bicarbonates (Wu et al., 2004). Biological clogging is due to algae, iron and sulfur slimes. De Kreij et al. (2003) found that drip-line with laminar flow suffers more severe clogging than the labyrinth type emitter having turbulent flow, because laminar flow is predisposed to clogging. Capra and Scicolone (2004) found that vortex emitters are more sensitive to clogging than labyrinth emitters.

Filtering can prevent inorganic particles and organic materials from entering the drip irrigation system. In India, mostly gravel media filter, screen and disk filters are used in drip irrigation system. Gravel media filter prevents passage of solid particles, have two internal auxiliary elements: the diffuser plate and the underdrains. The diffuser plate is responsible for the uniform distribution of the influent water over the filter bed surface. By directing the fluid flow lines perpendicular to the bed surface, the diffuser is often able to reduce the kinetic flow energy produced by water pumping, instead transforming this energy into potential energy, which prevents the sand particles from drifting, avoiding channels or creating fissures and sand surface mounds. The underdrains are responsible for allowing the passage of filtered water into the irrigation system, maintaining the sand layer within the filter and evenly distributing the reverse flow of water upward into the sand bed during the backwash process. Particles larger than the filter pores are captured by both physical and chemical mechanism (Adin and Alon, 1986).

Disk filter is simple, economical, and easy to manage and filtration is done at two stages. The larger outer surface operates as a screen filter and collects the larger particles. The grooves inside the disk allow the adhesion of fine particles, mainly organic matter. It retains the particles in the grooves of the disks. Capra and Scicolone (2004) observed that screen filters, either locally or internationally available, were not suitable for use with poor quality water with the exception of diluted and settled water. They also observed almost similar performance by disk and gravel media filter with treated municipal poor quality water.

Subsurface drip irrigation (SDI) systems diminish human exposure to harmful elements enter in the aerosols but have a higher initial investment cost, and need careful and consistent operation, maintenance and management. It 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 because they are too small for typical economical filtration. 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).

To minimize the buildup of sediment and organic residues, regular flushing of drip irrigation systems is recommended. The system should be designed such that the mainline, laterals and valves are sized to permit a sufficient flushing velocity (0.3 m sec^{-1}) recommended by ASAE (2003). Flushing valves should be installed at the end of mains, sub-mains, and flush-lines (if present). The flush-lines provisions should be made for flushing individual laterals that connect the downstream ends of the laterals. A regular maintenance program of inspection and flushing will help significantly in preventing emitter clogging. Therefore, drip-line flushing is periodically needed to remove these particles and organisms that are accumulated within the laterals (Ravina et al., 1992). The irrigation system should be designed so that it can be flushed properly. To be effective, flushing must be done at frequent intervals at appropriate velocity to dislodge and transport the accumulated sediments (Nakayama et al., 2007). Several researchers have different opinion about flushing frequencies: daily (Ravina et al., 1997), twice per week (Tajrishy et al., 1994) and once per week Hills et al., 2000; Tajrishy et al., 1994) with a secondary clarified effluent, every two weeks with stored effluents (Ravina et al., 1997) and with a secondary effluent (Hills and Brenes, 2001) or fortnightly and monthly with stored groundwater (Hills et al., 2000). However, in many areas, only one flushing is carried out at the beginning and/or at the ending of irrigation season.

In India, poor quality water from pond, canal and aquifer is frequently used by the farmers for agricultural production especially horticultural crops. There is need to develop the methodology for utilizing groundwater through drip irrigation system with filtration and flushing. Investigation is needed to conduct field trials on drip irrigation system by placing emitter laterals on surface and subsurface conditions under different filtration and flushing strategies. The objectives of this article were the effects of filtration and flushing on clogging of surface and subsurface placed emitters in drip irrigation system.

MATERIALS AND METHODS

Source of Irrigation Water

Water source for irrigation was groundwater. It was withdrawn through a tubewell penetrated into an aquifer at 40-45 m depth at New Delhi, India. The preservation and transportation of collected water samples were performed according to the standard methods (APHA, 2005). Collected irrigation water samples were analyzed for pH, electrical conductivity (EC), total solids (dissolved and undissolved), turbidity, calcium, magnesium, carbonate, and bicarbonate, according to the standard methods (APHA, 2005).

Experimental Set-up

To perform the process of irrigation drip irrigation system was installed with in-line lateral (10 mm diameter) with emitter spacing at 40 cm. It was laid on the ground for surface drip and was placed at a 15 cm depth from ground surface for subsurface drip (SDI). System included: 1. Sand media filter (T1) of size 50 mm, and with back flush mechanism; 2. Disk filter (T2) of 50 mm size, 130 microns. Irrigation water was allowed to pass through filters T1 and T2 alone as well as in combination of both the filters (T3). Main line (50 mm diameter) was connected to sub-mains (35 mm diameter) for each of the plots through a gate valve.

Particle Removal Experiment

Irrigation water collected from the tube well was stored in a tank constructed on the ground surface to make the water free from sediment coming from the aquifer. Then, the stored ground water was supplied to drip irrigation system to perform the different treatments (T1, T2, and T3). The centrifugal pump attached to drip irrigation system was operated for the smaller duration to generate the operating pressure in the main, submain and lateral line. In this process the air available in the system gets out. The discharge water was collected from the emitter for the duration of 360 second. To reduce the error generated in collection of discharged water. Quantity of flow of water from drip emitter was collected in containers at normal operating pressure of 1 kg cm^{-2}. Water collection from same emitter was repeated for four times. The flow rate was estimated by dividing total volume collected by the duration time of collection. The measurement was taken from randomly located sampling emitters for performance evaluation. Discharge from subsurface drip irrigation laterals were measured by excavating the soil around the buried drip irrigation laterals so that an emitter is visible with sufficient space below it for placement of the container to collect discharged water from it. This process was suggested by Magwenzi (2001). Performance of system was evaluated at normal operating pressure to discharge sufficient water for infiltration and to avoid ponding near the emitter. As per manufactures' recommendation, operating pressure of 1 kg cm^{-2} was considered adequate. To achieve accurate pressure, emitter level measurement was done at the lateral with precision digital pressure gage.

To improve the discharge from emitters flushing operation was carried out in main line, sub main line and the lateral pipes. It was continued at double the operating pressure until clean water runs from the flushed line for the duration of 360 seconds. Flushing operation was done at the end of the crop season. Discharge from emitters under different treatments was measured before and after flushing operation and emitter performance evaluation parameters were estimated.

Performance Evaluation of Filtration System

Performance of filters were evaluated by estimating the Filtration efficiency (F) of the filters, using Equ. 1.

$$F(\%) = \frac{N_0 - N}{N_0} \times 100 \qquad \text{.......(1])}$$

Where, N_0 is a value of specific quality parameter of unfiltered wastewater and N is the value of the same parameter after filtration.

Evaluation of Parameters for Emitter Performance

Uniformity coefficient (UC)

Several methods are available for assessing the uniformity of water application through drip irrigation systems. The term emission uniformity has generally been used to describe the uniformity of emitter flow rate for a drip irrigation system. Emission uniformity can be a function of: (1) hydraulic variation caused by elevation changes and friction losses along distribution lines and (2) emitter discharge variation at a given operating pressure caused by manufacturing variability, clogging, water temperature changes and aging. In the present study UC was estimated by using the following equation.

$$UC = 100\left[1 - \frac{\frac{1}{n}\sum_{i=1}^{n}|q_i - q|}{q}\right] \quad \text{……[2]}$$

Where, q_i = the measured discharge of emitter i (lh^{-1}); q = the mean discharge at drip lateral (l/h); and n = the total number of emitters evaluated.

Emitter flow rate (% of initial, R)

$$R = \frac{q}{q_{ini}}100 \quad \text{…..(3)}$$

Where: q = the mean emitter discharges of each lateral (l/h); and q_{ini} = corresponding mean discharge of new emitters at the same operating pressure.

Statistical Analysis

Statistical analysis was carried out using the GLM procedure of the SAS statistical package (SAS Institute, Cary, NC, USA). The model used for analysis of variance (ANOVA) included filtration of water from different filters and placement of lateral as fixed effects and interaction between filtered water and emitter placement depth. The ANOVA was performed at probabilities of 0.05 or less level of significance to determine whether significant differences existed among treatment means.

RESULTS AND DISCUSSIONS

Filter Performance

Filtration efficiency by filters T1, T2, and their combinations (T3) during the experiments are presented in Table 1. Filtration efficiency 14.3±8.8% for turbidity and 7.21±6.23% for total solids were achieved with T3. The value for TS under treatment (T1) was -3.13±14.5. It shows the variation in filtration efficiency from -17.63% to 11.37%. This was due to variation in amount of TS available in irrigation water and as testing was done for the same filter without cleaning. Sometimes, if filter was not cleaned and irrigation water containing lower TS was passed through T1 then TS available in T1 came out with the water coming out of filter in main line for irrigation. Thus the amount of TS available in the irrigation water was higher and resulted in negative filtration efficiency using Equation [1]. Similar reasoning can be made for negative filtration efficiency in case of Mg through T1. Negative filtration efficiency was also observed by Duran-Ros et al. (2009) with screen and disk filter for turbidity and TS. Duran-Ros et al. (2009) observed 12.42±23.53% filtration efficiency for turbidity and 8.47±18.36% for total suspended solids (TSS) with combination of screen and disk filter at 500 kPa inlet pressure with wastewater. In the present study filtration efficiency was lower than wastewater as groundwater fed to drip irrigation system to evaluate the performance of filters. Combination filter (T3) and lower inlet pressure caused more effective filtration. Combination filter gave best results for removal of bicarbonate (HCO_3) and carbonate (CO_3) in comparison to T2. However, filtration efficiency obtained through T1 was close to T3. Therefore T1 and T3 are not significantly different (P=0.261) as shown in Table1.

Table 1.Filtration efficiency and P value for difference in filtration of different water quality parameters.

Quality parameter	Filtration Efficiency (%) (mean and SD)			P value for LSD at $\alpha = 0.05$		
	T1	T2	T3	T1-T2	T1-T3	T2-T3
Turbidity	11.1±9.5	13.9±5.6	14.3±8.8	0.048	0.019	0.267
Total Solids, TS	-3.13±14.5	2.66±18.2	7.21±6.23	0.264	0.071	0.183
Calcium	6.49±2.63	1.53±6.7	8.04±7.45	0.536	0.316	0.467
Magnesium	-1.43±3.84	5.31±1.6	7.19±3.16	0.016	0.011	0.521
Carbonate	5.47±3.13	12.7±8.2	13.36±8.96	0.145	0.126	0.628
Bicarbonate	16.3±9.31	13.6±8.6	15.3±4.67	0.029	0.261	0.079

Removal of turbidity was highest with combination filter (T3) but it was close to T2. It can be seen that T1-T3 were significantly different (P=0.019) but T2-T3 were not significantly different (P=0.267). Effect of filtration systems was not significantly different for removal of CO_3, Ca, and total solids from the groundwater. The small filtration efficiencies by filters were in agreement with other published works (Adin and Elimelech, 1989; Ribeiro et al., 2008). Capra and Scicolone (2004) observed similar performance by disk and media filters. In sand filters, the smaller effective size of sand particles has effect on the sand filtration efficiency (Ives,1980). The combined filtration system always gave better results than individual filters e.g. T1 and T2.

Evaluation of Emitter Flow Rate

Emitter flow rate variations were evaluated with Analysis of Variance (ANOVA) by maintaining no variationin pressure so that the flow rate variation will only be affected by the clogging of emitters. ANOVA for variations in average flow rate under different filtration systems for beginning, end of season and after flushing are presented in Table 2.

Table 2.Significance level (P-value) of the statistical model and of each factor and interaction for emitter flow rate.

Parameter	Time		
	Beginning	End of season	After flushing
Model	*** (R^2=0.92)	***(R^2=0.87)	** (R^2=0.81)
Filter (T)	n.s.	***	**
Emitter placement (EP)	n.s.	*	n.s.
T × EP	n.s.	***	**
n.s. : not significant, P> 0.05; * : P< 0.05; ** : P< 0.01; *** :P< 0.001.			

Maximum reduction in flow rate (9.46%) was observed with filter T1 under subsurface drip while the minimum (6.28%) with combination filter. Reduction in flow rate with T2 was 6.83%, which is between the values of T1 and T3 as mentioned above (Fig. 1). Effect of filtration system as well as emitter placements are factors responsible for emitter flow rate and subsequently emitter clogging. The results from statistical analysis revealed that, after the end of crop season, there was significant effect of filter, emitter placement and their interaction. At the beginning of the experiment there was no significant effect of emitter placement and their interaction with filter. It is obvious because emitters were new at the beginning and had negligible chance of clogging. After continuous use of the system, clogging takes place and effect of different filtration systems starts affecting the flow rate. After flushing, filtration systems were significantly different but emitter placement was non-significant. But interaction of filtration system with emitter placement was significant ($P < 0.01$). Good filtration system can control these inconsistent results. This indicated clogging to be a dynamic phenomenon and to change with space and time (Ravina et al.,1992).

Effect of Flushing and Filtration Systems on Emitter Discharge

The effect of flushing and different filtration system on emitter discharge is presented in Figure 1. Flushing of main, sub-main and lateral removes the accumulation of sediments, dislodge bacterial slime and biofilms. Flushing was effective to improve the discharge rate of emitters supplied through gravel media, disk and combination filters. Maximum effectiveness in improving the discharge was observed under T1 in surface irrigated drip laterals (2.78%). Surface placement of lateral with T2 shows least improvement (0.44%). It may be due to better filtration from T2, which is also evident from the filtration efficiency of filters. Overall, higher improvements in flow rate of emitters under subsurface placed lateral were more than surface placed lateral in all the filtration system. It may be due to flushing of soil particles from emitters under higher water velocity in the path of emitters. Based on the findings of this study, it can be recommended that pressure compensating emitter can perform better over the nonpressure compensating emitters. It is also recommend that an air/vacuum relief valve be used for subsurface drip irrigation to avoid ingestion of soil particles due to back siphoning. Higher flushing frequency can give better results when it is performed at smaller duration as compared to present study it was done at the end of the irrigation season. To control the emitter clogging, acidification can also work but it causes acidification of soil after long time application of acid flushing (Nakayama and Bucks, 1991).

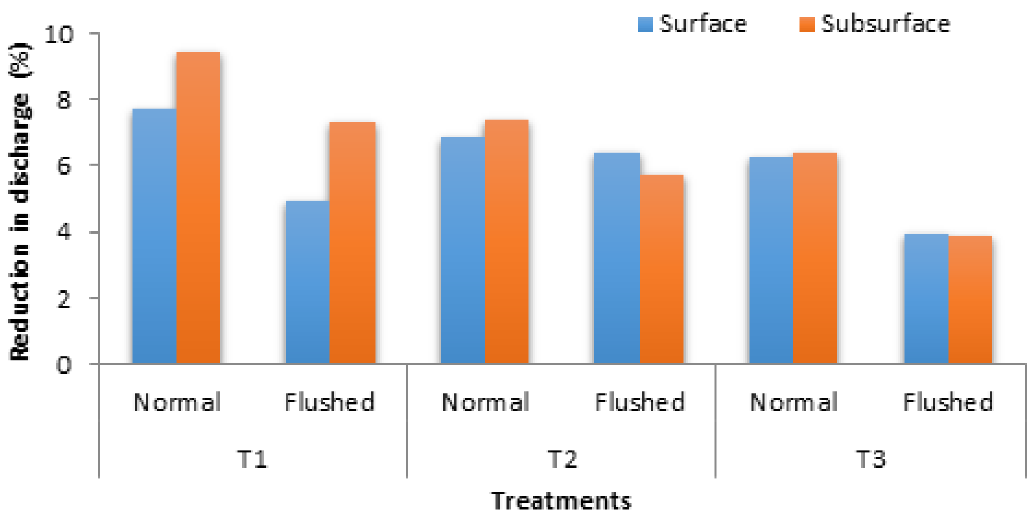

Fig 1. Effect of flushing and different filtration systems on reduction in emitter discharge.

Effect of Flushing on Uniformity Coefficients

Variations in uniformity coefficients (UC) are presented in Table 3. Highest UC was observed at beginning of the field experiment. After end of the crop season, UC was decreases significantly. However, performance of surface and subsurface drip irrigation system using both filters combination comes under good category because UC was more than 95%. Similar observations were made by Puig-Bargues et al. (2005) with poor quality water.

Table 3. Uniformity coefficient resulting from the performance evaluation of drip irrigation system.

Filter	Depth of placement of lateral	UC (%)		
		Beginning	End of season	After flushing
Gravel media (T1)	Surface	98.59	95.06	96.41
	Subsurface	98.56	94.13	95.49
Disk (T2)	Surface	98.89	96.12	96.64
	Subsurface	98.91	95.00	96.27
Combination filter (T3)	Surface	99.01	96.27	97.31
	Subsurface	99.05	94.86	96.07

At the end of season, surface and subsurface drip with combination filters shows highest UC 96.27% and 94.86%, respectively. It indicates that irrigation water with combination filters can give better filtration in comparison with single filters. Significant improvement in UC was observed after flushing of the system. Higher improvement in UC was observed in subsurface drip in comparison to surface drip after flushing (Table 3). The main reason for higher improvements in the UC of emitters due to way out of ingested external soil particles above the laterals, which may stuck in the biofilm at the emitter outlet leading to increased clogging. Installation of air/vacuum relief valves at the high elevation points can help prevent soil ingestion in subsurface drip irrigation system (Lamm and Camp, 2007). Acidification and chlorination have been found to be effective in reducing clogging caused by biofilm growth (Ravina et al.,1997); Tajrishy et al.,1994).Chemical treatments such as acidification can be also used for increasing chlorination effectiveness (Nakayama et al., 2007).

CONCLUSIONS

Subsurface drip irrigation emitters experienced more clogging under different filtration system and revealed that filtration with a combination of gravel media and disk filter was most appropriate strategy against emitter clogging. It resulted in a better emission uniformity and reasonable lower reduction in emitter flow rate. Filters can be used for significant removal of for turbidity, total solids, carbonate and bicarbonate available in poor quality water for irrigation. Filter, emitter placement and their interaction have significant effect on emitter clogging. Flushing is helpful in partial removal of emitter clogging. It gives significant improvement in discharge and uniformity coefficient. This revealed that the flushing at double the operating pressure is adequate when it was performed at the end of the crop irrigation season. Pressure compensating emitters may be good choice over the non-pressure one to reduce the influence of clogging. It is also recommend that an air/vacuum relief valves should be the compulsory component with subsurface drip irrigation to avoid ingestion of soil particles due to formation of soil solution in the profile of soil above the emitter.

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