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Research Article

Emitter Clogging and Hydraulic Performance of Drip System under Different Water Qualities and Placement Techniques

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Abstract: The present study was conducted at the Indian Agricultural Research Institute, New Delhi, India, to evaluate the effect of sand-disc filters, pressure compensating (bioline) and non-pressure compensating (inline) emitters, and surface and subsurface placement of laterals on emitter clogging using wastewater and groundwater for irrigation. Results of this study revealed that besides water quality, the type of emitter, placement of laterals, and emitter position on laterals affected emitter's clogging. The major cause of clogging was associated with the precipitated substance accumulated at the emitter inlet concurrently close the micro-pore channels of the emitter, consequently reduce the emitter discharge. The major substances that took part in the clogging of emitter were EC, pH, HCO_3, Turbidity, total solid, *Escherichia coli* (*E. coli*), and total coliform. It was observed that these substances (HCO_3, Turbidity, total solid, *E. coli*, and total coliform) of groundwater and wastewater were categorized with a medium risk of clogging except for magnesium (low risk of clogging). Pressure compensating drip emitter showed better performance against clogging as compared to non-pressure compensating drip emitter. Sub-surface placement of drip emitter was more prone to clogging under both wastewater and groundwater. It was observed a significant ($p \leq 0.05$) effect of lateral placement, emitter types, and the interaction between these factors on emitter's clogging under both types of water. Emitter flow rate decreased with the increasing time of operation of the drip systems at normal operating pressure, because of clogging of emitters. By flushing operation, it was observed a 3 to 5% higher flow rate in inline drip emitter than bioline (1-2%). The R^2 value, which precisely describes the head-discharge relationship, was high (0.99) in most of the bioline treatments. This study also observed and recommended that pressure compensating emitter would be the most appropriate technique to reduce the clogging while using wastewater for irrigation. Flushing effectively controlled the emitter's clogging thus improved the emitter's water discharge rate.

***Keywords*:** wastewater, surface and subsurface placement, pressure compensating and non-pressure compensating emitter, emitters clogging

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1. Introduction

Water demand is increasing because of the fast population growth, improvement in living standards, along with growth in industry and urbanization. The freshwater for irrigation use is declining rapidly, while the demand for the same is increasing continuously [1-2]. There is a significant challenge to produce more food for the growing population from limited water. Therefore, the efficient use of irrigation water is of paramount importance for sustainable agricultural development [3-4]. Because of the increasing migration of the rural population towards urban areas, the flow of household wastewater into the water bodies has increased, which has led to various environmental problems [5]. Although wastewater contains various pollutants, it is also rich in nutrients that benefit plant growth [6]. Hence, an efficient way to use wastewater from an environmental point of view is to use it in agriculture. In many parts of the world, including India, wastewater is used for irrigation in various land-use systems such as pastures, forests, parks, and golf courses [7] and vegetable cultivation [8]. A drip irrigation system can reduce the risks associated with wastewater use, such as plant toxicity, water pollution, and direct contact with irrigation devices and consumer products [9]. However, filter clogging and emissions are the major problems seen under drip irrigation systems when using wastewater [10]. The dripper, the filtration process, the morphological and chemical composition of the suspended particles, etc. directly affect the emitter blockage [11]. The clogging of emitters and filters mainly comprises three types (1) physical clogging: caused by the deposition of sand, silt, and clay particles together with debris [12], (2) chemical clogging: because of the interaction of dissolved solids with each other to form calcium carbonate deposits [13] and (3) biological clogging: because of algae, iron mud, and sulfur slurries in the water [14-15]. Tertiary treatment and chlorination are two effective methods to reduce the clogging of drip emitters but have been costly [16]. The filtration unit is the heart of the drip irrigation system because it removes impurities from water, which helps to avoid emitter clogging [10]. But most of the time, the filter gets clogged due to low-quality water [17]. The most commonly used filtration systems in India are sand media filters, disc filters, and screen filters (Tripathi et al., 2014) [7]. Sand media filter which prevents the passing of suspended solids larger than the filter pour is useful for water having a high suspended solids content [18-19]. A disc filter is used for water having organic materials and fitted after the sand media filter, while a screen filter is lightweight, simple, and economic, but it is restrictedly used only for quality groundwater and settled wastewater [20]. The combined use of the sand-disk filter is a very effective strategy to improve the removal efficiency of the filtration system [21].

Along with filtration systems, emitter design is also a key factor to reduce the clogging of emitters. Various types of anti-clogging emitter designs such as tube emitter system with laminar flow [22-23], labyrinth type emitter [21], and dripper having high flow [24] have also been developed. However, flushing the laterals in the regular interval has also been effective to reduce the clogging of emitters. Flushing the laterals even once a month had a significant impact against emitter clogging compared to no flushing [25]. Wastewater application through the drip system results in higher installation and operation costs owing to the clogging of emitters and filters [26]. Because of the serious scarcity of fresh water for irrigation, the wastewater can be used efficiently for irrigation through the drip system, but it is necessary to overcome the problems of clogging of emitters and filters [27]. For this purpose, performing different emitters can be evaluated; simultaneously, some adjustments in the installation of the filters can be done. Research on drip irrigation always focused to reduce clogging problems of emitters and filters using wastewater for irrigation through some modifications in the operation of emitters, however, these studies have mostly been conducted in laboratories [28-29] while in the open field case, clogging of emitters and filters appears to be a more serious problem [30-31]. The present study evaluated the effect of different emitters, sand disc filters, and placement techniques of drip laterals on clogging of emitters when wastewater and groundwater are used for irrigation through a drip system.

2. Materials and methods

2.1 *Experimental site & climatic conditions*

The study was conducted at the Precision Farming Development Centre of Indian Agricultural Research Institute (IARI), New Delhi, India. The experimental field is located at 28°38′11″N, 77°09′54″E. The location had a subtropical semiarid with hot dry summer and cold winter. The mean annual temperature is 24 °C, which varied from 45 °C in June and 7 °C in January. The mean annual rainfall based on 100 years record (1901-2000) is 790 mm.

2.2 *Experimental setup*

A plot measuring 51 m × 30 m was selected for the experiments. The plot was divided into two units of 25 m × 30 m each with a 1 m buffer strip. Each plot comprised four treatments, which were repeated thrice. Treatments were designed in a factorial randomized block design as shown in Table 1. Lateral lines were spaced at 60 cm apart, which was laid on the plant row, and emitters spacing was 40 cm (plant to plant spacing was also 30 cm). The total number of drippers in each lateral line was 75. The detailed descriptions of the drip system and experimental site are mentioned by [9].

Table 1. Detail of the experimental treatments

Treatments	Detail
T1	Groundwater application in inline surface drip
T2	Groundwater application using inline subsurface drip
T3	Groundwater application using bio line surface drip
T4	Groundwater application using bio line subsurface drip
T5	Wastewater application using inline surface drip
T6	Wastewater application using inline subsurface drip
T7	Wastewater application using bio line surface drip
T8	Wastewater application using bio line subsurface drip

Note: Inline: non-pressure compensating emitter, Bioline: pressure compensating emitter
Surface drip: lateral placement at the ground surface, subsurface drip: lateral placement inside the ground (30 cm below the ground).

2.3 *Operational procedure*

Wastewater was collected from a sewage line that runs approximately 500 meters from the experimental field. Two wastewater collection tanks were established, one of them near the sewage line to hold the wastewater for one day to remove floating material and allow suspended particles to settle. The second tank was established near the experimental site to collect the deposited wastewater from the first tank to improve the quality of wastewater by reducing suspended particles. Wastewater from the second tank was applied to the experimental plots through different filtration systems (sand media filter and disc filter) to prevent the clogging of the drip system and to reduce the microbial population [21].

The performance of the system was evaluated at an operating pressure of 1 kg × cm^{-2} to provide sufficient irrigation water for the soil type (sandy-loam) to avoid ponding near the root zone of the crop [9]. A digital pressure gauge was used to measure the pressure at the laterals and at the emitters to maintain an accurate pressure of the system. A catch-can method was applied to measure the required quantity of water to check the flow rate of the emitters. Whereas in the case of subsurface drip placement, the flow rate of emitters was analyzed using the method given by [32]. The flushing of the system after the experiment by dispersing groundwater and wastewater by operating the system at 2 kg × cm^{-2} for 10 minutes. Immediately after flushing, the emitter flow rate was measured.

2.4 *Evaluation of filter performance*

The performance of the filter was evaluated by estimating the removal efficiency of the filtration systems using the following equation.

$$RE = (N_0 - N) / N_0 \tag{1}$$

where N_0 is a measured quality parameter at the filter inlet; and N is the same parameter at the filter outlet.

2.5 *Assessment of emitter performance*

2.5.1 *Head-discharge relationship of drippers*

Head-discharge relationship of drippers can be characterized by drawing a relationship between dripper flow rate Vs applied pressure head using curve fitted equation as follows:

$$q = CH^x \tag{2}$$

where, q is a dripper flow rate ($m^3 \times s^{-1}$), H is the pressure head (m), x represents dipper exponent characteristics and C is emitter coefficient.

2.5.2 *Coefficient of variation* (CV_q)

The CV_q in the emitter flow rate was estimated using the Eq. (3) [13].

$$CVq = SD / q \times 100 \tag{3}$$

where SD is the standard deviation of dripper discharge ($L \times h^{-1}$) and q is the mean discharge of emitters in the same lateral ($L \times h^{-1}$).

2.5.3 *Discharge variation*

The dripper discharge variation (R) from the percentage of the initial discharge was estimated using the following equation:

$$R = \left(\frac{q}{q_{ini}} \right) \times 100 \tag{4}$$

where q is the mean emitter discharge and q_{ini} is the initial discharge of the dripper. During, the measurement of the discharge from the dripper, and the operating pressure should be the same for both conditions.

2.5.4 *Distribution uniformity* (DU)

DU of the drip system was calculated by adopting the procedure of [33] as mentioned below:

$$DU = \frac{q_{25}}{q} \times 100 \tag{5}$$

where q is the mean flow rate of all the dripper tested ($L \times h^{-1}$) and q_{25} is the mean flow rate of the dripper (the lowest discharge of the 25% drippers) ($L \times h^{-1}$).

2.5.5 *Observation of the emitter*

The visual analysis of clogging of drip emitters at the beginning and end of the experiment was also performed. The emitters were cut and examined externally with the help of a photograph taken by the microscope.

2.6 *Statistical analysis*

A factorial randomized block design was applied in the experimental field with eight treatments which were three factors at two levels i.e. factors: water types, placement of drip laterals, and type of drip laterals. Analysis of variance (ANOVA) analyzed the data using full factorial procedures by SPSS (16) software. The treatment's mean was compared by the Tukey test at a p-value of 0.05 or less.

3. Results and discussion

3.1 *Irrigation water quality*

Table 2. Physio-chemical and biological analyzes for groundwater and wastewater, with the classification for risk of clogging

Parameters	Unit	Wastewater	Groundwater
		Mean ± SD	Mean ± SD
pH	-	6.89 ± 0.16*a	7.4 ± 0.19*a
EC	$dS \times m^{-1}$	1.70 ± 0.18**a	2.17 ± 0.26**a
HCO_3	$mg \times L^{-1}$	410.5 ± 32.82**a	369.2 ± 43.13*a
Turbidity	NTU	44.0 ± 10.12#	1.50 ± 0.13#
Ca	$mg \times L^{-1}$	95.23 ± 23.80**ab	44.58 ± 6.24*ab
Mg	$mg \times L^{-1}$	32.59 ± 5.12*ac	35.28 ± 4.35*ac
Total solids	$mg \times L^{-1}$	852.21 ± 117.83**bc	939.28 ± 154.78**bc
E.coli	$CFU \times mL^{-1}$	347124 ± 28457***ab	nd
Total coliform	$MPN \times mL^{-1}$	135484 ± 33871***ab	nd
BOD_5	$mg \times L^{-1}$	126 ± 30.24#	0.725 ± 0.10#

nd: not detected, *low risk of clogging, **medium risk of clogging, ***high risk of clogging, #not available. Classification according to a-Ayers and Wistcot, 1991; b-Capra and Scicolone, 1998; c-Nakayama et al., 2007

The average values of these main clogging parameters and categorization of their respective risk of clogging for irrigation waters are presented in Table 2. Electrical conductivity (EC) and pH values for wastewater were lower than the groundwater. Variation in the EC values for groundwater was from 1.92 to 2.43 $dS \times m^{-1}$ with an average of 2.17 $dS \times m^{-1}$ but for wastewater, it was in the range of 1.48 to 1.88 $dS \times m^{-1}$ with a mean of 1.70 $dS \times m^{-1}$. Whereas, pH values varied from 7.21 to 7.6 for groundwater with an average of 7.40 higher than wastewater (mean value 6.89). The average value of bicarbonate for wastewater and groundwater was 410.5 $mg \times L^{-1}$ and 369.2 $mg \times L^{-1}$ respectively. The calcium value of wastewater and groundwater was recorded at 95.23 and 44.58 $mg \times L^{-1}$ respectively. *E. Coli* was found in order of 10^{-6} $CFU \times ml^{-1}$ and Total coliform also having a similar order of magnitude in wastewater. BOD_5 value in wastewater was observed 126 $mg \times L^{-1}$. The main emitter clogging agents present in groundwater and wastewater were categorized based on the category suggested by [34] and verified through physicochemical and biological analyses. As the pH value of wastewater indicating slightly acidic than groundwater. Both the water had the low risk of clogging category which showed that this parameter may not directly influence the clogging but helps in biological growth and chemical reaction [7]. The EC value in wastewater was lower than the groundwater likely due to less salt content in wastewater indicating a lower risk of clogging than groundwater [4]. Bicarbonate and turbidity of wastewater were much higher than the groundwater, maybe due to the presence of foreign particles, and carbonate gets converted into bicarbonate

[20]. This was indicated that the presence of a high level of bicarbonate and turbidity in wastewater was more prone to clogging i.e. medium to high-risk clogging category (Table 2). The magnesium content in wastewater was lower than in groundwater. The biological parameters such as *Escherichia coli* (*E. coli*) and Total coliforms showed a high risk of clogging in wastewater, whereas in groundwater they were not detected. Almost all physio-chemical parameters of groundwater and wastewater were categorized with a medium risk of clogging except for pH and magnesium (low risk of clogging). Based on the above water quality attributes, the application of wastewater was more prone to clogging than the groundwater.

3.2 *Filter performance*

The removal efficiency of the sand-disc filter for groundwater and wastewater during the experiment is shown in Table 3. The higher removal efficiency was observed for turbidity (34.74 ± 5.56%) and the total solid (21.83 ± 3.27%) in wastewater application. The overall average removal efficiency was observed to be 12.41 ± 3.10% and 7.31 ± 1.31% for wastewater and groundwater, respectively. It was observed that the maximum removal efficiency of *Escherichia coli* (42.97 ± 10.31%) and total coliform (48.79 ± 11.23%) in wastewater. The removal efficiency of biological oxygen demand was 5.67 ± 1.53% for wastewater and 5.51 ± 1.04% for groundwater. Some reduction in organic matter contaminant through the filtration was also observed. The sand-disc filter lowered the EC at a higher rate in wastewater than groundwater, while removal efficiency of pH was less in wastewater than groundwater. By utilizing the filtration system, the clogging risk was reduced. The filtration system was lowered the EC and pH by 3 to 6% whereas, bicarbonate and turbidity were lowered by 18 to 34% in wastewater. The removal efficiency of these parameters was well within the results reported by other researchers [8, 17]. These total solid and turbidity removal efficiencies help in lowering the physical clogging risks in drip emitters [10]. The removal efficiency of 84.60 ± 1.88% for *E. coli* and 95.24 ± 3.39% for total coliform with sand-disc filters using wastewater [7]. A reduction in organic materials using sand-disc filters, reducing the clogging level in the drip system was reported by [15]. Other research findings also support the present results [35]. Hence, it was recorded that the combined use of sand-disc filters reduces the risk of clogging in drip irrigation systems.

Table 3. The mean and standard deviation of the removal efficiency of both the water parameters obtained by the combined sand-disc filtration system

Parameters	Wastewater	Groundwater
	Mean ± SD	Mean ± SD
pH	6.31 ± 0.95	6.47 ± 0.90
EC	3.59 ± 0.47	3.46 ± 0.42
HCO_3	18.58 ± 2.60	19.14 ± 3.04
Turbidity	34.74 ± 5.56	5.74 ± 0.98
Ca	12.19 ± 02.07	10.23 ± 1.64
Mg	12.41 ± 3.10	7.31 ± 1.31
Total solids	21.83 ± 3.27	18.12 ± 3.80
E.coli	42.97 ± 10.31	nd
Total coliform	48.79 ± 11.23	nd
BOD_5	5.67 ± 1.53	5.51 ± 1.04

nd: not detected

3.3 *Assessment of emitter performance*

3.3.1 *Head-discharge relationship of emitters*

Table 4. Head-discharge relationships under different experimental treatments

Treatment	Stage	Coefficient	Exponent	R^2
T1	B	3.585	0.455	0.99
	BSY	3.524	0.455	0.99
	ASY	3.498	0.451	0.99
T2	B	3.565	0.443	0.99
	BSY	3.534	0.442	0.99
	ASY	3.458	0.441	0.99
T3	B	3.595	0.499	0.99
	BSY	3.544	0.496	0.99
	ASY	3.488	0.494	0.99
T4	B	3.575	0.498	0.99
	BSY	3.514	0.495	0.99
	ASY	3.508	0.493	0.99
T5	B	3.455	0.442	0.99
	BSY	3.424	0.445	0.99
	ASY	3.418	0.441	0.98
T6	B	3.445	0.442	0.99
	BSY	3.423	0.439	0.99
	ASY	3.417	0.436	0.98
T7	B	3.585	0.499	0.99
	BSY	3.543	0.494	0.99
	ASY	3.476	0.492	0.99
T8	B	3.554	0.498	0.99
	BSY	3.497	0.494	0.99
	ASY	3.487	0.491	0.99

B-beginning of the experiment, BSY-beginning of the second year of the experiment, ASY-after completion of the second year of the experiment

Head-discharge relationships were derived at the beginning of the experiment, at the beginning of the second year of the experiment, and after completion of the experiment (second year) for all the treatments. It was found that the small values of emitter coefficients with inline drip emitters as compared to bioline, which showed that inline drip emitters are more vulnerable to clogging. The subsurface emitters showed more susceptibility to clogging as compared to surface drip laterals in both wastewater and groundwater. The emitter coefficient was found lower in all the treatments at the end of the second year of the experiment (Table 4). At normal operating pressure, the exponent for inline emitters and subsurface drip laterals was lower than the bioline emitter and surface drip laterals. Overall, bioline emitter along with surface placement of laterals reduced clogging of the emitter. The flow rate of emitters is controlled by the hydraulic pressure at the emitter and the flow path dimension of the emitter. As for manufacture design, the exponent x is 0.50 when the flow through the emitter is considered as fully turbulent with a manufacture's design exponent of 0.5 [36-37]. In the present study, two types of emitters were used as pressure compensating and non-pressure compensating. The flow rate variability was negligible at a beginning of the experiment, which means there was no turbulence effect on the flow rate on both the emitters. At the end of the second year of the experiment, we found small values of emitter coefficients with inline drip emitters as compared to bioline, which showed that inline drip emitters are more vulnerable to clogging. Furthermore, subsurface placed emitters also showed more susceptibility to clogging as compared to surface drip laterals in both waste and groundwater. Some researchers also observed a more clogging risk of non-pressure compensating drip emitters as compared to pressure compensating using wastewater [10, 15]. The bioline has a pressure compensating mechanism which helped the lateral to run without clogging regarding varying heads. However, such a mechanism was not present in the inline drip lateral [6]. The R^2 value which precisely describes the head-discharge relationship was high (0.99) in most of the bioline treatments. Overall, bioline emitter along with surface placement of laterals reduced clogging of the emitter.

3.3.2 *Emitter flow rate and emitter location*

Table 5. Significant level (p-value) of the statistical model and each factor and interaction for flow rate variability and its variation during the experiment

Factor and Interaction	B	BSY	ASY
Model	ns	**	***
Water	ns	***	***
Depth	ns	*	**
System	ns	**	***
Water × Depth	ns	*	***
Water × System	ns	***	***
Depth × System	ns	ns	**
Water × Depth × System	ns	***	***

ns: non-significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$
B-beginning of the experiment, BSY-beginning of the second year of the experiment, ASY-after completion of the second year of the experiment

The variation in emitter flow rate was recorded with taking care of the pressure variation, so that flow rate reduction can only be explained by clogging of emitters. The average flow rate variations during the study period under different emitters for both types of water are presented in Figure 1a, 1b and 1c. At the beginning of the experiment, flow rate variation was equal to the initial flow rate given by the manufacturer (Figure 1a). But after the first year, the flow rate was reduced in all the treatments (Figure 1b). It was observed that the maximum reduction in wastewater flow rate with inline emitter and subsurface placement of laterals while the minimum flow rate of groundwater was recorded in bioline and surface placement of drip lateral. The interaction effect of different parameters on the flow rate of the emitter is presented in Table 5. A significant effect of lateral placement, emitter types, and their interaction was observed on emitters clogging in both types of water. Dripper flow rate variation study was done by maintaining constant pressure to the drip systems, so that any changes in the flow rate can be explained only by the clogging of the dripper. The results of the statistical analysis showed that at the beginning of the experiment there was hardly any significant difference was found among the depth, placement, and type of lateral are likely due to new drippers has a negligible chance of clogging [7, 17]. This result can also be validated by DU which had the value almost near to manufacturer-designed values at the beginning of the experiment (Figure 2). After the end of the experimental period, a highly significant difference was observed among the interaction effects of the depth, placement, and type of lateral. This is due to the continuous use of wastewater which was having medium to high risk of clogging potential (Table 2). Moreover, in the first year of the experiment, the CV was less than the recommended limit (10.0%), which is rated good as per [38]. But in the second year, CV was higher than the prescribed limit [38] in the case of using wastewater with inline laterals, indicating that inline is more prone to clogging. Results also revealed that the bioline drip laterals showed excellent performance as per the prescribed limit in both the years over inline drip laterals.

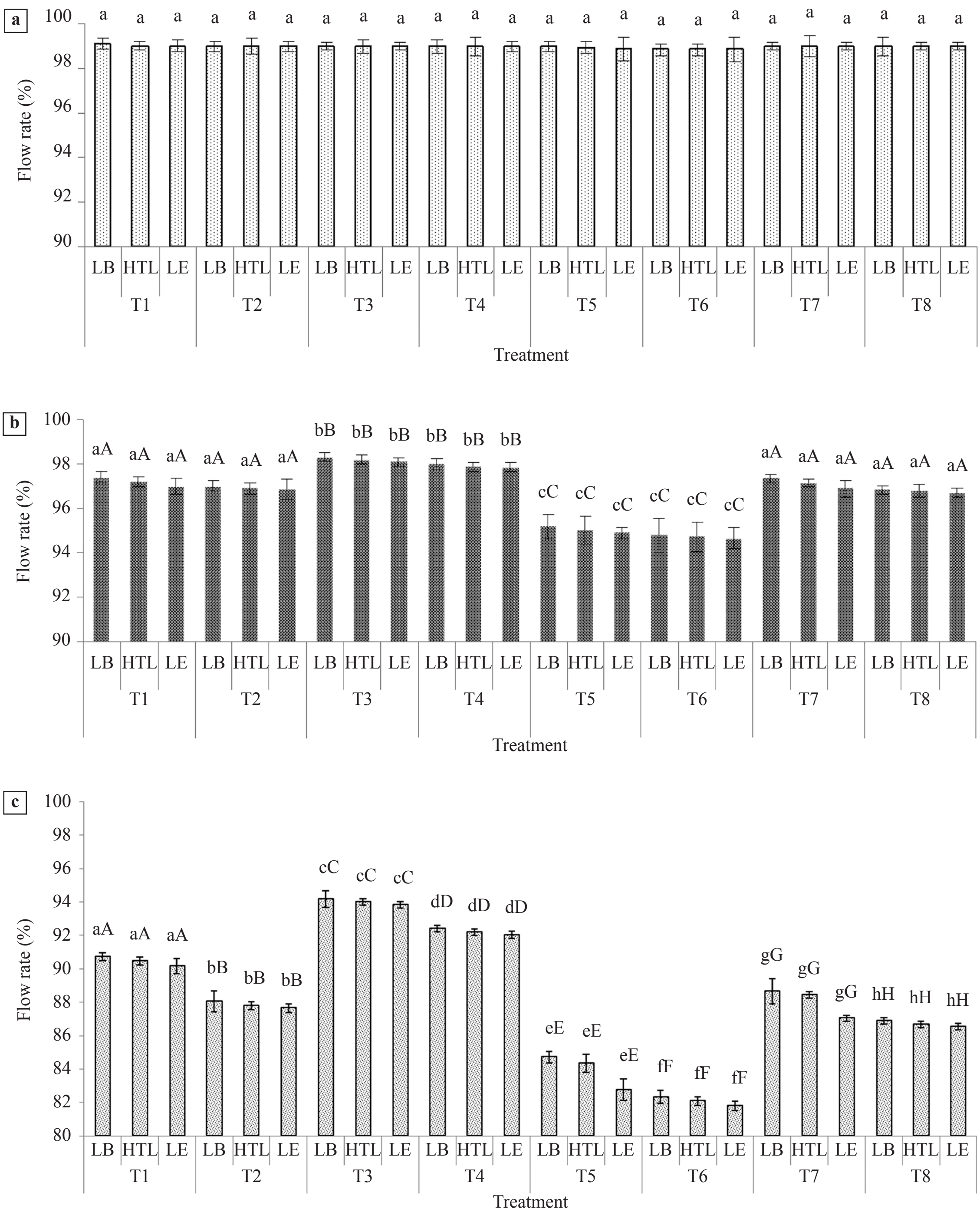


Figure 1. Average flow rate and standard deviation of the emitters and their location under different treatments during the study period
Different small letters mean significant differences at $P < 0.05$ among the emitter location, while different capital letters mean significant differences at $P < 0.05$ among the treatments. LB-emitter at the lateral beginning, HTL-emitter at half of the total length, and LE-emitter at the lateral end.

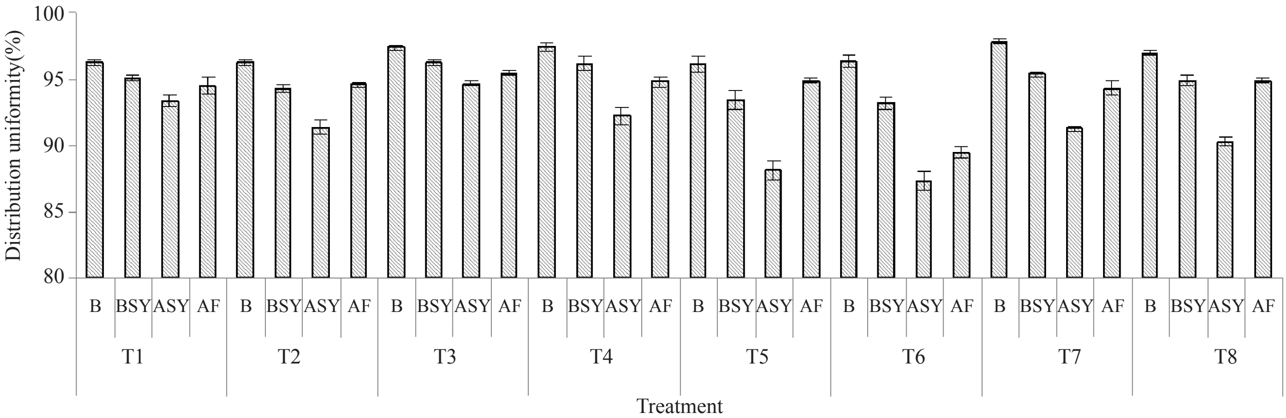


Figure 2. Distribution uniformity and standard deviation of the emitters discharge and their location under different treatments during the study period for performance evaluation of drip irrigation system. B-at the beginning of the first year of the experiment, BSY-at the beginning of the second year of the experiment, ASY-at the end of the second year of the experiment, and AF-after flushing

3.3.3 *Coefficient of variation of emitter discharge along with the location*

The coefficient of variation (CV) of dripper discharge is depicted in Figures 3a, 3b and 3c. There was no CV observed during the beginning of the experiment when a new drip system was installed (Figure 3a). After 1 year of the experiment, the maximum CV of 5.2% was found in inline drip lateral and the minimum was 1.7% in bioline drip lateral (Figure 3b). CV along the drip lateral was also recorded. A 3% CV was found between the first and last emitter within the same bioline drip laterals using groundwater, while 10.1% CV was observed with inline drip laterals using wastewater. A maximum of 13.75% CV was observed in inline drip laterals with subsurface using wastewater. Subsurface emitters showed poor performance in both the years over surface placement with higher CV (Figure 3c). After flushing, the improvement in the flow rate variation was observed in all the treatments. This may be attributed due to the flushing of the lateral removed the accumulation of sediment, which helped in reducing the clogging of emitters, and consequently, the flow rate was improved in all the treatments (Figure 1a-c).

3.3.4 *Distribution uniformity (DU) and observation of the emitter*

The distribution uniformity of surface and subsurface placement of drip laterals using wastewater and groundwater is presented in Figure 2. At the beginning of the field experiment, the highest distribution uniformity was observed, whereas distribution uniformity decreased considerably onwards the completion of the experiment. Minimum distribution uniformity (87.3%) was observed in inline drip laterals with subsurface placement using wastewater while maximum (97.39%) in the surface placement of bioline drip lateral using groundwater. Overall, distribution uniformity was improved by 3% to 5% by flushing the inline drip lateral. The state of different emitters at the beginning (at the time of transplanting) and at end of the tests (after the second year of the experiment) are shown in Figure 4. The deposition was visible in both the drip emitters. Inline drip emitter had some more dirt at inlet point as compared to bioline drip emitter. At the end of the experiment, a solid deposit was observed in both types of the emitter (bioline and inline) using the wastewater. Similar results were also recorded by [15, 36, 39]. In the present study, a biological film and physical material were found in a very less quantity in the laterals and emitters dispersing wastewater. Among all treatments, bioline drip laterals showed a higher value of DU and the lowest value of CV. The distribution uniformity of a drip system increased by 5% by single flushing at the end of the experiment [40]. Flushing of bioline drip lateral could improve only 1% to 2% distribution uniformity. [25] found a similar result in the case of pressure compensating drip laterals using a sand-disc filtration system by flushing. Subsurface placement of emitters showed poor distribution uniformity over surface placement. At the end of the laterals, the flow rate variation was highest which indicated a greater number of dripper clogging occurred due to lower velocity at this point allow the particles to settle down [9, 41].

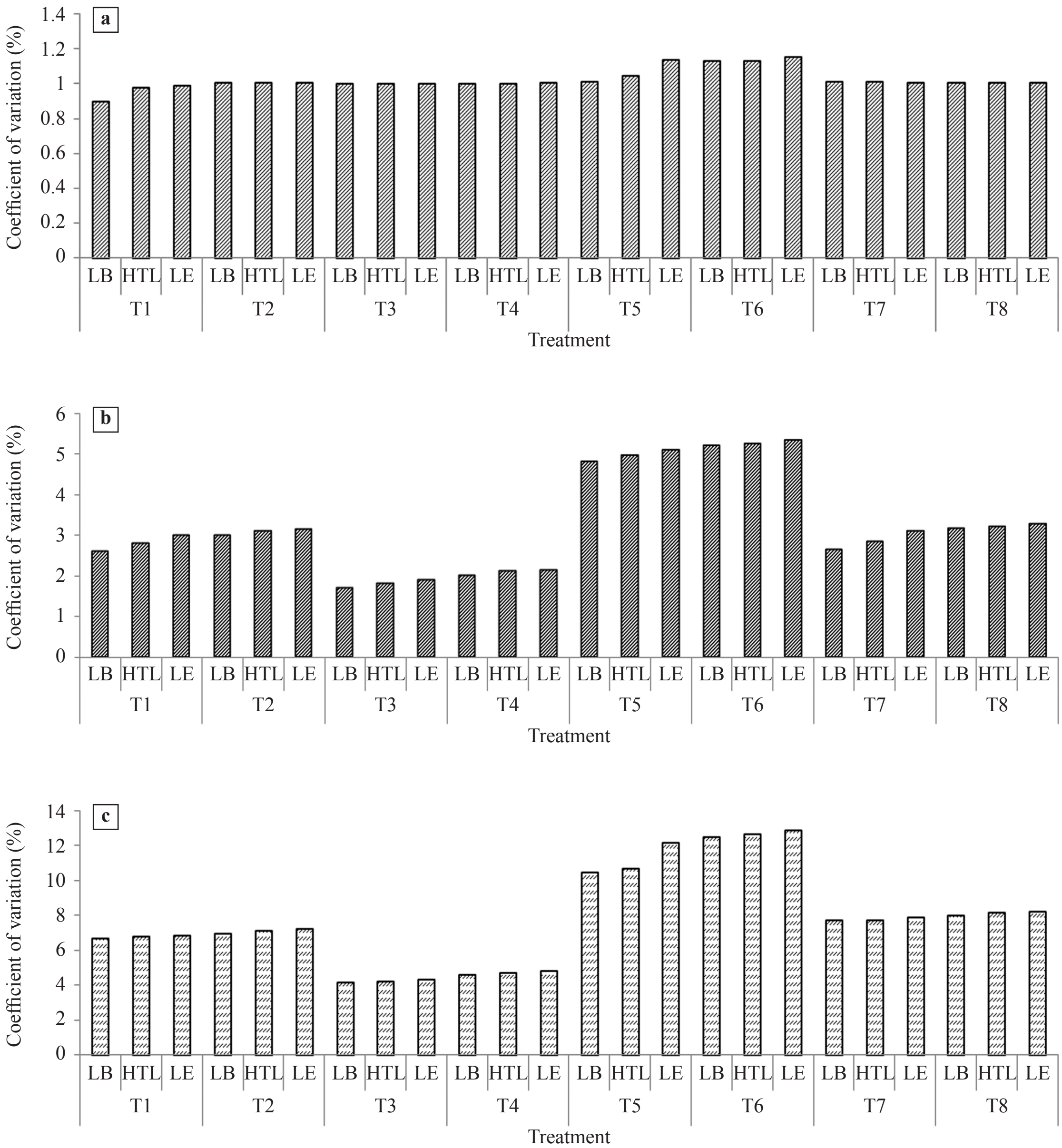
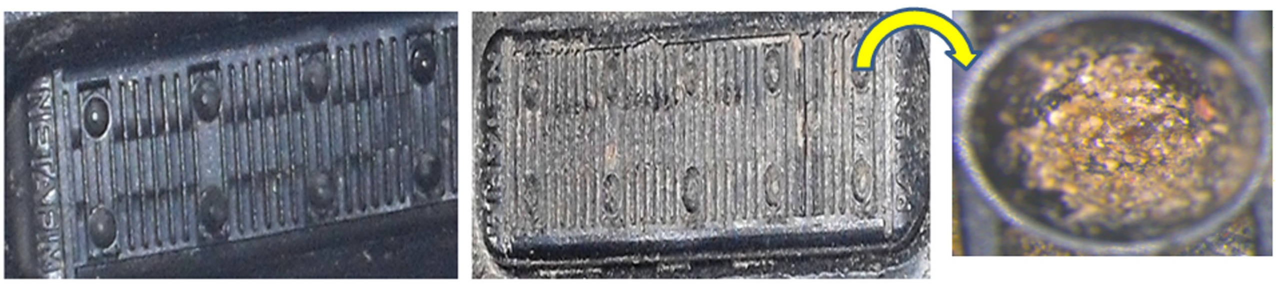


Figure 3. Coefficient of variation and standard deviation of the emitter's discharge and their location under different treatments during the study period

LB-emitter at the lateral beginning, HTL-emitter at half of the total length, and LE-emitter at the lateral end



a b 1

Figure 4. Internal view of bioline and inline emitters at different stages
a-bioline emitter at the time of transplanting (beginning of the experiment), b-bioline emitter at the harvesting stage (after the second year), c-inline emitter at the time of transplanting (beginning of the experiment), and d-inline emitter at the harvesting stage (after the second year). 1 and 2 are the microscopic view of bioline and inline emitters.

4. Conclusions

The present study aimed to assess the effects of type of emitters, depth of lateral placement, and water quality on clogging of the emitter and sand-disk filter. The major substances that participated in the clogging of emitter were EC, pH, HCO_3, Turbidity, Ca, Mg, total solid, *E. coli,* and total coliform. It was observed that these substances (EC, HCO_3, Turbidity, Ca, total solid, *E.coli*, and total coliform) of wastewater were categorized with a medium risk of clogging except for pH and magnesium (low risk of clogging). Results showed that the clogging of pressure compensating as compared to non-pressure compensating dripper presented a moderate clogging hazard while the interaction of emitter type with flushing treatment showed minor clogging hazard. The best hydraulic performance revealed that the pressure compensating emitter in combination with surface placement and sand-disc filter would be the most appropriate strategy to cope with emitter clogging when using wastewater. This combination also resulted in reasonably good distribution uniformity with a greater emitter discharge exponent. Flushing was found to be an effective means to control emitter clogging and improve emitter discharge.

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Conflict of interest

The authors declare that they have no conflict of interest.

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