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OPTIMIZING CHLORINE USE FOR IMPROVING PERFORMANCE OF DRIP IRRIGATION SYSTEM UNDER BIOLOGICALLY CONTAMINATED WATER SOURCE

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Emitter clogging in drip irrigation, caused by poor water quality and inadequate system operating pressure, can affect the distribution uniformity of emitters and may cause inadequate irrigation applications. The objective of this study was to evaluate efficiency of different concentrations and schedules of chlorination to clean emitters for improving distribution uniformity. This study was conducted on drip irrigation system, installed in citrus orchard at experimental area of Water Management Research Centre, University of Agriculture, Faisalabad. The physical and chemical analysis along with bacteriological counts were carried out for water source of particular drip irrigation system. The results showed that water has biologically severe potential to clog emitters, and consequently partial clogging of emitters was apparent due to presence of sticky bacteria layers and in field performance of particular drip irrigation system was suboptimal in terms of selected performance parameters. To improve the said system performance, five concentrations of sodium hypochlorite (C1: 30 ppm, C2: 60 ppm, C3: 100 ppm, C4: 150 ppm, C5: 200 ppm) and three schedules (S1: five times/month, S2: three times/month and S3: two times/month) were used for chlorination process. The comparative analysis indicated that after application of treatments, performance parameters such as coefficient of variation (Cv), emission uniformity (Eu) and statistical uniformity (Us) were improved from 0.221 to 0.097, 61.3 to 82.0% and 77.9 to 90.3%, respectively. The statistical analysis further showed that treatments with C1: 30 ppm and C2: 60 ppm were not effective to achieve the required performance targets. While, the treatments with C3:100 ppm, C4:150 ppm and C5:200 ppm showed the best performance in the order of S1: five times/month, S2: three times/month and S3: two times/month, respectively.

Keywords: Emitter clogging, water quality, chlorination, coefficient of variation, emission uniformity, statistical uniformity

INTRODUCTION

A quantum jump in crop productivity can be achieved only by shifting from conventional to conservation agriculture by improving water use efficiency. Drip irrigation, being a proven technology, has offered special agronomical, economical, and agro-technical advantages for efficient use of water and labor (Keller and Bliesner, 1990; Keller, 2002) and it can replace flood irrigation having 60% application efficiency with an efficiency of 90% (FAO, 1988). Clogging of emitters, however, has been a major problem with the use of drip irrigation systems (Capra and Scicolone, 1998; Niu *et al*., 2012; Pei *et al*., 2014) especially when fertilizers are also applied through the system or when irrigation system operate under an inadequate pressure (Yavuz *et al*., 2010).
The emitter clogging also depends on quality of water source (Duran-Ros *et al*., 2009) for drip irrigation system as poor water quality contributes towards emitter clogging. Source of water may be surface or groundwater. Clogging of emitters can be categorized into physical, chemical and biological. Bacterial growth and algae are major problems associated with surface water usage. These algae content form aggregates that can clog emitters (Dehghanisanij *et al*., 2005; Haman *et al*., 1987; Juanico *et al*., 1995). Proper chlorination having an adequate concentration is the key to control clogging of emitters due to biological impurities such as bacteria, algae and fungi (Cararo *et al*., 2006). There is no consensus among researchers in relation to amount, frequency and the best way of application for chlorination (Airoldi, 2007). Therefore this study has been designed to investigate the effect of amount and application frequency of chlorination to clean biologically chocked emitters in drip irrigation system. The specific objectives of the study were to analyze the quality of water source for drip irrigation system for identifying the potential emitter clogging factors, and to optimize the use of chlorination in terms of its concentration and schedules for improving drip irrigation system performance.

MATERIALS AND METHODS

***Study area and drip irrigation system specifications*:** The study was conducted on drip irrigation system, installed in citrus orchard on 0.8 ha at the experimental area of Water Management Research Centre (WMRC), University of Agriculture; Faisalabad, located along Jhang road (latitude

31.38721, longitude 73.01195) during 2012. The drip irrigation system was installed on a total area of 4 ha at WMRC farm with the specifications given in Table 1. The schematic diagram of subject drip irrigation system is shown in Figure 1.The system has a water storage pond with a capacity of 44 m^3 (5.5 x 4 x 2) m. The canal and tubewell water was stored in storage pond for operation of drip irrigation system according to irrigation scheduling.

Table 1. Drip irrigation system specifications.

Component/Item	Specification
Electric motor	7.5 hp
Pump (centrifugal) to pump water from pond	8.8 lps, 30 m
Hydro-cyclone filter	Height 1 m Remove particles with SG >2.65
Sand media filter	140 gpm, Filtering media 0.15 m^3, Gravel size 4-6 mm dia
Screen filter	100 Micron, 150 Mesh
Main and Sun-main pipe (pvc)	50.8 mm
Lateral pipe	16 mm
Emitter (Non PC, Point source)	4 lph

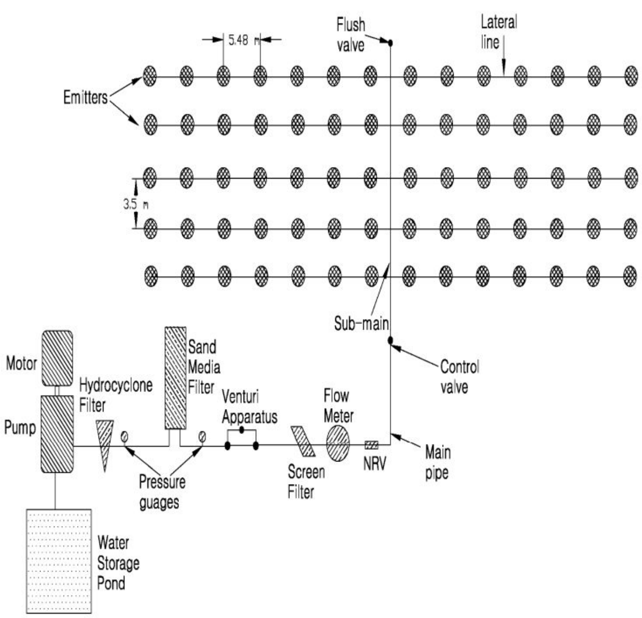

Figure 1. Schematic diagram of drip irrigation system.

***Water quality and emitters analysis*:** Complete analyses (Physical, Chemical and biological) of irrigation water from water storage pond of drip irrigation system was carried out at PCRWR Lab, Faisalabad and Microbiology Lab, University of Agriculture, Faisalabad, to investigate emitter clogging potential of water according to criteria, given by Storlie (1995) (Table 2). The analysis of fifty drip emitters, selected randomly from whole citrus field was also carried out at Microbiology Lab, University of Agriculture, Faisalabad, to check emitters clogging.

Table 2. Water quality classification relative to its potential for drip emitter clogging.

Potential problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Suspended solids	mg/l	<50	50-100	>100
pH		<7	7-7.5	>7.5
Dissolved solids	mg/l	<500	500-2000	>2000
Manganese	mg/l	<0.1	0.1-1.5	>1.5
Iron	mg/l	<0.1	0.1-1.5	>1.5
Hardness as $CaCO_3$	mg/l	<150	150-300	>300
Bacterial population	#/mL	10000	10000-50000	>50000

Source: Storlie (1995)

***Layout of the experiment*:** The orchard field was of 95 x 85 m^2 in size. Total 45 laterals of drip irrigation system, spaced at 3.5 m were selected for experimental investigation. There were eight plants on one lateral spaced at 5.48 m. Four plants on one lateral (2nd plant, 4th plant, 6th plant and 8th plant) were selected as subject plants for study. Every plant had four emitters spaced at 10 cm. The discharges of 16 emitters were observed from each lateral. Each treatment was practiced on one lateral as single replication. Total 45 laterals and 720 emitters were studied to check the treatments effect during the experiment. The detailed layout of experiment is shown in Figure 2.

***Treatments for chlorination*:** After analysis of water from storage pond, chlorination was selected to clean the drip emitters in drip irrigation system, as chlorination is the most common method to kill bacterial slimes (Camberato and Lopez, 2010; Obreza, 2004; Raudales *et al.*, 2014). Sodium hypochlorite NaCLO (household breach) was used for chlorination purpose due to its low cost and easy market availability. Sodium hypochlorite comes in liquid form with 5 to 15 percent chlorine. For experiment, Sodium hypochlorite with 15 percent chlorine was selected. To find out the optimum amount and timing of chlorination, five concentrations and three different schedules of chlorination were selected for cleaning of the system. These five concentrations of chlorine were as C1: 30 ppm, C2: 60 ppm, C3: 100 ppm, C4: 150 ppm, C5: 200 ppm and three different schedules were as S1: five times/month (Every sixth day), S2: three times/month (Every tenth day) and S3: two times/month (Every fifteenth day).

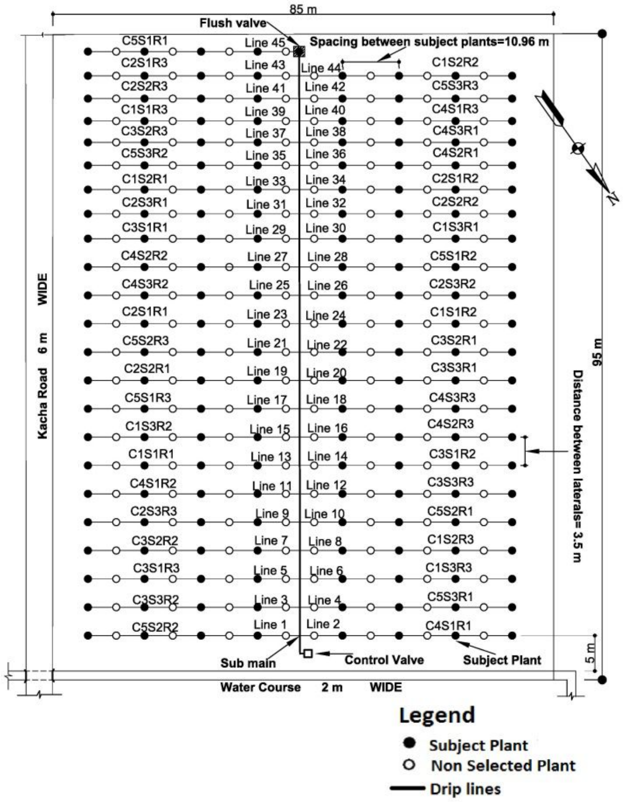

Figure 2. Layout of the experiment.

C1= 30 ppm, C2= 60 ppm, C3= 100 ppm, C4=150 ppm, C5=200 ppm, S1= Five times/month, S2= Three times/month, S3= Two times/month, R1= Replication 1, R2= Replication 2, R3= Replication 3

Total fifteen treatments viz. T1: C1S1 (30 ppm with five times/month), T2: C1S2 (30 ppm with three times/month), T3: C1S3 (30 ppm with two times/month), T4: C2S1 (60 ppm with five times/month), T5: C2S2 (60 ppm with three times/month), T6: C2S3 (60 ppm with two times/month), T7: C3S1(100 ppm with five times/month), T8: C3S2 (100 ppm with three times/month), T9: C3S3 (100 ppm with two times/month), T10: C4S1 (150 ppm with five times/month), T11: C4S2 (150 ppm with three times/month), T12: C4S3 (150 ppm with two times/month), T13: C5S1 (200 ppm with five times/month), T14: C5S2 (200 ppm with three times/month), T15: C5S3 (200 ppm with two times/month) were designed according to these concentrations and schedules of chlorination. Each treatment has three replications (Figure 2).

***Chlorine injection*:** According to the treatments concentration, the required injection rate of chlorine was calculated using the formula as given in equation 1 (Pitts *et al.*, 1990) .

$$I = \frac{(0.006 * P * Q)}{m} \qquad Eq. (1)$$

Where I = gallons of liquid sodium hypochlorite injected per hour; P = ppm desired; Q = system flow rate in gpm; m= Percent chlorine in the source.

The chlorine was injected into drip system through venturi apparatus. The injection of chlorine solution was continued for the length of time required to fill the subject laterals with this solution. The time required to fill the subject lateral was determined by detecting chlorine in the water, discharged from emitters by "Chlorine detection strips" and then system was shut down. Chlorine solution was allowed to stay in laterals for 24 hours. After 24 hours, end caps of laterals were opened and system was started to flush the laterals. To monitor the effect of each treatment after flushing the system, end caps of laterals were closed and again drip system was started to note discharge of each emitter of subject plant on the lateral.

***Drip performance*:** The discharge of the emitters was collected under 1 bar pressure, for the purpose of testing the emitter's performance under existing conditions and after the treatment.

The performance indicators used to evaluate drip irrigation system were coefficient of variation (Cv), emission uniformity (Eu) and statistical uniformity (Us) of system (Yavuz *et al*., 2010).

***Coefficient of variation*:** Coefficient of variation was measured by using equation 2 (ASABE, 2002).

$$C_v = \frac{S}{X_a} \qquad Eq. (2)$$

Where C_v = Coefficient of variation; S = Standard deviation of emitters discharge; X_a = Average flow of emitters (Lph)

The criteria for coefficient of variation is given in Table 3.

Table 3. Criteria for coefficient of variation (Cv) of emitters.

Emitter Type	Cv Range	Classification
Point source drip emitters and micro sprinklers	<0.05	Excellent
	0.05 to 0.07	Average
	0.07 to 0.11	Marginal
	0.11 to 0.15	Poor
	> 0.15	Unacceptable
Line source drip tube	<0.10	Good
	0.10 to 0.20	Average
	>0.20	Marginal to Unacceptable

Source: ASABE (2003)

Standard deviation: The standard deviation was calculated as below:

$$S = \left[\frac{\sum_{i=1}^{n}(x_i - X_a)^2}{n-1}\right]^{1/2} \qquad Eq.(3)$$

This formula used by Yavuz *et al*. (2010).

Where S= Standard deviation of emitters discharge; x_i= Emitter flow (Lph); X_a= Average flow of emitters (Lph); n= Number of emitters.

Emission uniformity: Emission uniformity (Eu) shows uniformity of the emitters under constant pressure (ASABE, 1994). To calculate E_u equation 4 was used (Keller and Karmeli, 1974):

$$E_u = 100\left(1 - \frac{1.27C_v}{\sqrt{n}}\right)\frac{X_n}{X_a} \qquad \text{Eq. (4)}$$

Where Eu=System emission uniformity (%); Cv=Coefficient of variation; n= Number of emitters per plant; X_n=The lowest flow of emitter (Lph); X_a= Average flow of emitters (Lph);

The criteria for emission uniformity is given in Table 4.

Table 4. Criteria for emission uniformity (Eu) of emitters.

Eu Range (%)	Classification
94 to100	Perfect
81 to 87	Good
68 to 75	Tolerable
56 to 62	Very bad
Below 50	Unacceptable

Source: ASABE (1994)

Statistical uniformity: The statistical uniformity for emitters was calculated using equation 5 (Bralts and Kesner, 1983).

$$U_s = 100\left(1 - \frac{S}{X_a}\right) \qquad Eq.(5)$$

Where Us=Statistical uniformity (%); S= Standard deviation of emitters discharge; X_a= Average flow of emitters (Lph)

The criteria for statistical uniformity is given in Table 5.

Table 5. Criteria for statistical uniformity of emitters.

Us Range (%)	Classification
95 to 100	Perfect
85 to 90	Good
75 to 80	Tolerable
65 to 70	Very bad
Below 60	Unacceptable

Source: ASABE (1994)

RESULTS AND DISCUSSION

The water quality analysis (Table 6) showed that water used for drip irrigation system had no physical emitter clogging potential due to very low suspended solids loading rate (<50 mg/L). Also, the analysis showed that water has chemically minor potential to clog emitters as dissolved solids, manganese level and iron level in water were 408 mg/L, 0.04 mg/L and 0.08 mg/L, respectively, which were below clogging potential of water (Table 2) but pH value of water was 7.1, which lies in marginal clogging range and has slight potential to clog emitters (Table 2). Hardness as $CaCO_3$ had no contribution in emitter clogging. The biological bacterial count, however, showed severe potential to clog the emitters (620000/ml). The summary of results for water quality analysis is given in Table 6.

Table 6. Results of water quality analysis.

Potential problems	Units	Analysis results	Remarks
Physical			
Suspended solids	mg/L	10	None
Chemical			
pH		7.1	Slight to moderate
Dissolved solids	mg/L	408	None
Manganese	mg/L	0.04	None
Iron	mg/L	0.08	None
Hardness as $CaCO_3$	mg/L	110	None
Biological			
Bacterial population	#/mL	620000	Severe

The analysis of fifty drip emitters, selected randomly from drip irrigation system showed that bacteria's were accumulated in the small orifice of emitters due to their sticky nature and the emitters were partially clogged and were unable to deliver the designed discharge (Fig. 3-5).

After the application of treatments (Chlorination), overall performance of drip irrigation system was improved. Similar results have also been observed by Li *et al*. (2012). The Statistix 8.1 software was used for analysis of variance technique under CRD. Average emitters discharge (before and after the treatment) under each concentration and schedule with significant ($p<0.05$) effects are shown in Table 7. The emitters discharge under the treatment with concentration C5 (200 ppm) showed the non-significant results for S1 (five times/month), S2 (three times/month) and S3 (two times/month) schedules. Treatments with concentration C4 (150 ppm) showed the significant results for Schedule S3, but non-significant results for schedules S1 and S2. The average discharge of emitters under the treatments with concentration C3 (100 ppm) and C2 (60 ppm) showed the significant results for all three schedules i.e. S1, S2 and S3. Treatments with concentration C1 (30 ppm) showed the significant results for schedule S1 but schedule S2 and S3 were non-significant from each other.

Overall average drip irrigation system performance was found as the best with chlorine concentration C5 (200 ppm) and significantly better than C4 (150 ppm), C3 (100 ppm), C2 (60 ppm) and C1 (30 ppm). Moreover, overall average

Table 7. Effect of treatments under different concentrations and schedules of chlorination on discharge of drip emitters (Lph).

Schedule	Chlorination concentration					
	C1 (30 ppm)	C2 (60 ppm)	C3 (100ppm)	C4 (150 ppm)	C5(200 ppm)	Average
S1 (Five times/month)	6.0533 d	6.4433 b	6.6783 a	6.7250 a	6.6683 a	6.5137 a
S2 (Three times/month)	5.7917 ef	6.0900 d	6.4450 b	6.6867 a	6.7633 a	6.3553 b
S3 (Two times/month)	5.7167 f	5.8467 e	6.2700 c	6.4617 b	6.7600 a	6.2110 c
Average	5.8539 e	6.1267 d	6.4644 c	6.6244 b	6.7306 a	

Treatments bearing same letters do not differ significantly ($p<0.05$).

Table 8. Comparison of average performance parameters of drip irrigation system.

Treatments		Cv (Coeff. of variation)			Eu (Emission Uniformity) %			Us (Statistical Uniformity) %		
		Before	After	Classification	Before	After	Classification	Before	After	Classification
T1	C1S1	0.225	0.160	Unacceptable	63.1	70.6	Tolerable	77.5	84.0	Tolerable
T2	C1S2	0.226	0.186	Unacceptable	61.7	68.5	Tolerable	77.4	81.4	Tolerable
T3	C1S3	0.223	0.198	Unacceptable	63.4	66.8	Very bad	77.7	80.2	Tolerable
T4	C2S1	0.235	0.106	Marginal	60.0	77.2	Tolerable	76.5	89.4	Good
T5	C2S2	0.225	0.146	Poor	64.2	74.0	Tolerable	77.7	85.4	Good
T6	C2S3	0.226	0.180	Unacceptable	66.0	72.1	Tolerable	77.4	82.0	Tolerable
T7	C3S1	0.228	0.033	Average	62.3	94.4	Perfect	77.2	96.7	Perfect
T8	C3S2	0.211	0.096	Marginal	57.2	75.5	Tolerable	78.9	90.4	Good
T9	C3S3	0.214	0.106	Marginal	61.9	76.5	Tolerable	78.6	89.4	Good
T10	C4S1	0.223	0.028	Excellent	63.3	94.7	Perfect	77.7	97.2	Perfect
T11	C4S2	0.215	0.037	Excellent	63.5	94.7	Perfect	78.5	96.3	Perfect
T12	C4S3	0.211	0.095	Marginal	62.5	79.8	Tolerable	78.9	90.5	Good
T13	C5S1	0.225	0.033	Excellent	57.3	94.8	Perfect	77.5	96.7	Perfect
T14	C5S2	0.202	0.029	Excellent	61.3	95.4	Perfect	79.8	97.1	Perfect
T15	C5S3	0.229	0.028	Excellent	52.5	95.0	Perfect	77.1	97.2	Perfect
Average	------	0.221	0.097	-------	61.3	82.0	-------	77.9	90.3	-------

C1= 30 ppm, C2= 60 ppm, C3= 100 ppm, C4=150 ppm, C5=200 ppm, S1=Five times/month, S2= Three times/month, S3= Two times/month

performance showed that the schedules S1 was more effective than S2 and S3 and schedule S2 was found better than S3.

The comparison between the average discharge of emitters before and after chlorination with different chlorine concentrations under schedules S1, S2 and S3 are shown in figures 3-5, respectively.

In schedule S1, a close agreement between average discharge values before and after applying treatments showed non-significant effect among the treatments with concentrations C5 (200 ppm), C4 (50 ppm) and C3 (100 ppm). While with schedule S1, treatments with C2 (60 ppm) and C1 (30 ppm) revealed significant effect as shown in Figure 3. In schedule S2, average discharge showed non-significant differences among treatments with concentration C5 (200 ppm) and C4 (50 ppm) while significant differences among treatments with concentrations C3 (100 ppm), C2 (60 ppm) and C1 (30 ppm) as shown in Figure 4.Treatments differed significantly for different chlorine concentrations under schedule S3 (Figure 5) and maximum improvement for average emitter discharge was recorded for C5 (200 ppm).

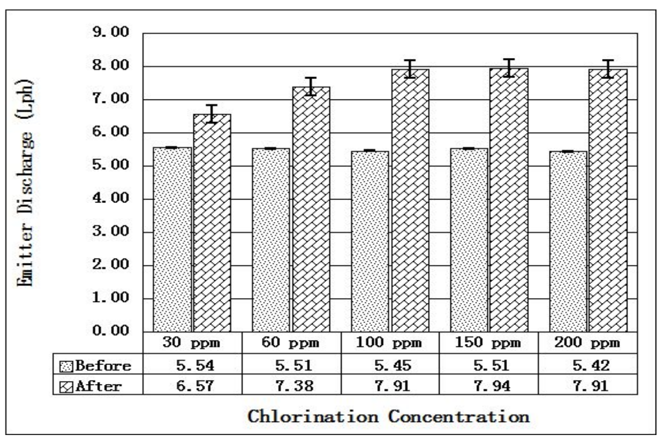

Figure 3. Improvement in emitters discharge before and after applying treatments under schedule S1 (five times/month).

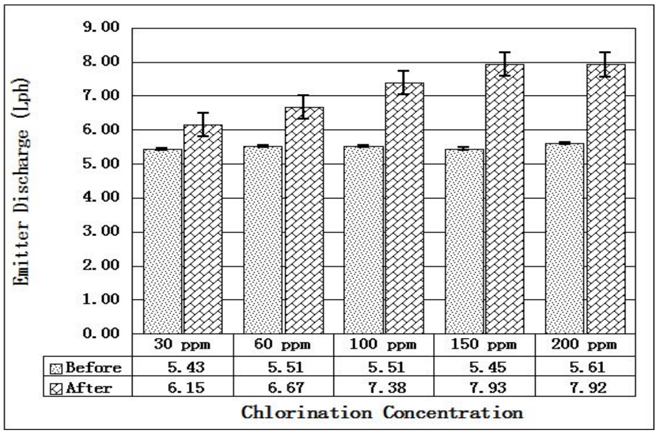

Figure 4. Improvement in emitters discharge before and after applying treatments under schedule S2 (three times/month).

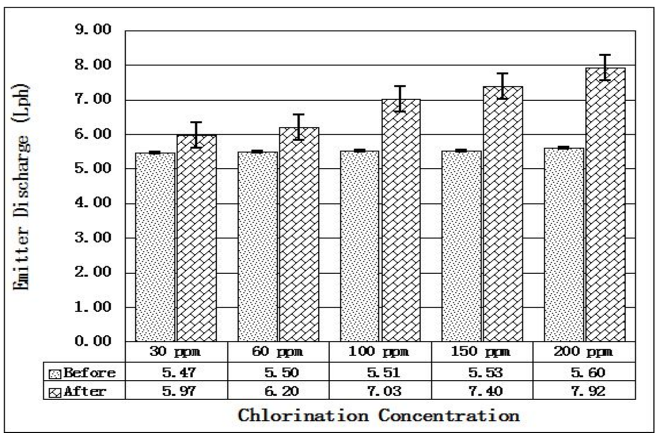

Figure 5. Improvement in emitters discharge before and after applying treatments under schedule S3 (two times/month).

Before starting application of chlorine, the performance parameters of drip irrigation system such as coefficient of variation (Cv), emission uniformity (Eu) and statistical uniformity (Us) were determined, whose average were 0.221, 61.3 % and 77.9 % respectively. After chlorination according to the designed concentrations and schedules, the performance parameters including Cv, Eu and Us improved and reached to a average of 0.097, 82.0 % and 90.3 % respectively. The average values of Cv, Eu and Us with their classification under fifteen treatments, before and after chlorination are given in Table 8.

The results (Table 8) showed that chlorination with concentrations C1 (30 ppm) and C2 (60 ppm) were not effective to achieve the required performance targets. The concentration C3 (100ppm) showed the best results for S1 (five times/month) because all performance parameters improved to an acceptable range. Concentration C4 (150 ppm) improved the performance parameters for both S1 and S2 (three times/month) but S2 is preferable because it is more practicable than S1. Concentration C5 (200 ppm) cleaned the system and improved the performance parameters for all schedules i.e S1, S2 and S3 (Two times/month) but S3 is again more practicable than S1 and S2.

***Conclusions*:** The source water from storage pond of drip irrigation system indicated that the water has biologically severe potential to clog the emitters and consequently partial clogging of emitters was apparent due to presence of sticky bacteria layers. It was concluded that to treat the clogged emitters, chlorine concentrations C1: 30 ppm and C2: 60 ppm were not effective to achieve the required performance targets. While, the chlorine concentrations C3:100 ppm, C4:150 ppm and C5:200 ppm showed the best performance in the order of S1: five times/month, S2: three times/month and S3: two times/month, respectively.

***Recommendation*:** Treat the clogged emitters of drip irrigation system under biologically contaminated water source with chlorine concentrations C3:100 ppm for S1: five times/month, C4:150 ppm for S2: three times/month and C5:200 ppm for S3: two times/month to improve the performance of drip irrigation system.

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