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Hydraulic Performance of Drip Emitters under Different Types of Emitters and Levels of water Salinity

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ABSTRACT

The study was carried out to assess the hydraulic performance of drip irrigation under indoor conditions. The treatments consist of three types of emitters (inline emitter, black and blue pressure compensating) and five levels of saline water (0.20, 0.35, 3.5, 5.0, and 5.75 dS/m). The hydraulic performance of the emitters was evaluated with reference to percentage of discharge reduction (R %), coefficient of discharge variation (CV %), Christiansen's uniformity coefficient (CU %), scheduling uniformity (SU), emission uniformity (EU %), application efficiency (EA %) and clogging percentage (P_{clog}%). The results showed that the black type pressure compensating emitters recorded significant ($P \leq 0.05$) decrease in R% and CV% for the five tested water qualities, and showed highest values of CU% for the well water. On the other hand, the inline emitters recorded the highest values of EU% and EA% for saline water of 5.0 ds/m salinity. The blue pressure compensating emitters showed the lowest clogging (P_{clog}%) for the five tested water qualities and lowest performance of EU% and EA% for the River Nile water 0.2, saline water 3.5, 5 and treated wastewater 5.75 dS/m, respectively. The black type pressure compensating and inline emitters showed no clogging. The study concluded that the emitter type and water quality are the main factors affecting the hydraulic performance of drip irrigation systems.

Keywords: Hydraulic performance; Irrigation efficiencies; Clogging**,** Salinity, Emitters.

INTRODUCTION

Drip irrigation system regularly and slowly applies water and fertilizers directly to the root zone of plants through a network of designed plastic pipes and low discharge emitters. The advantage of using a drip irrigation system is that it can significantly decrease soil evaporation and increase water use efficiency by creating a low wet area in the root zone. This technique of irrigation has a better efficiency of water use (Basso *et al.*, 2008), minimizing the negative environmental factors and becoming viable alternative for sustainable irrigated agriculture (Valipour, 2012; Bhattarai *et al.*, 2008). Due to water shortage in many parts of the world today, drip irrigation is becoming quite popular (Powell and Wright, 1998; Sahin *et al.*, 2005). In addition, drip irrigation systems have the advantage of fitting difficult topography (Wei *et al.*, 2003). In evaluation with surface and sprinkler irrigation systems, drip irrigation can achieve 90% or more application efficiency, which can hardly be achieved by the other systems (Michael, 1978). The phenomenon of clogging emitter has been widely studied (Taylor *et al*., 1995; Capra and Scicolone, 1998). The reasons for emitter clogging can be divided into three types: physical, chemical and biological clogging (Bucks *et al*., 1979). The reasons of clogging differ based on emitter dimension (Ahmed *et al*., 2007) and position in lateral lines (Ravina *et al*., 1997). Ravina *et al.*, (1997) found that fast flow can limit the biological growth on the pipe wall and thus lesser the hazard of clogging; emitters with high discharge rates clog less than those with low discharge rates over the same time; many clogged emitters are found at the tailing part than at the leading part of the drip lateral.

Investigate the hydraulic performance of drip emitters under indoor conditions using five levels of salinity water (0.20, 0.35, 3.5, 5.0, and 5.75 dS/m) it was the main goal of this study. Three types of emitters commonly used in Sudan were selected for the experiment. Two of them were online pressure compensating designated black &blue with different discharge and the third emitter type was an inline. Also the goal of this study was to determine the (Emitters discharge rate, Reduction, Coefficient of uniformity, Emission of uniformity and clogging percentage). Also to evaluate the hydraulic performance of the drip emitters at indoor conditions. On the other hand, salinity it is a general expression used to describe the levels of dissimilar salts such as calcium sulfates, sodium chloride, magnesium and bicarbonates.

MATERIALS AND METHODS

The conduct experiment was conducted during the period from December 2012 to June 2013 under laboratory conditions, in the Faculty of Agriculture, University of Khartoum, Shambat with coordinates of longitude 32.32 ºE, latitude 15.36 ºN and 380 m above mean sea level. The climate is semi-arid with low humidity and daily mean maximum temperature of 40°C in summer and 21°C in winter. The daily mean minimum temperature is 25°C in summer and 15°C in winter. Rainfall is about 160 mm mainly during July, August and September.(Sudan Meteorological department, 1951-1980). The treatments included three emitter types and five levels of salinity. The specifications of emitters were as follows: black on-line emitters of rated discharge 4 Lhr^{-1}, blue on-line emitters of rated discharge 8 Lh^{-1} and an inline (built in) emitters of rated discharge 4 Lh^{-1}. The details of salinity levels were as follow: Well water of salinity 0.35 dS/m WWS, river Nile water of salinity 0.20 dS/m RNW, salt of NaCl was added to raw river Nile water to give two levels of saline water SW, 3.5 dS/m SW1,5.0 dS/m SW2 and treated wastewater of salinity 5.75 dS/m TWWS.

Drip irrigation system layout was set up including water supply (Water tanks of about 3000 liters capacity, were used to store different types of water), a water tank of 10000 liters capacity was used to store treated wastewater, an electric motor ½ hp was used to pump irrigation water by a centrifugal pump from the tank, while the control unit consisted of the following: Two valves one before the pump to control the movement of water, and the other one after the pump to control the discharge, Pressure gauge fixed before water entering the lateral line to maintain constant pressure throughout the system; the constant pressure was maintained at (2 bars), Flushing system needed to clean the pipes (Figure.1). The mainline pipe was 4 m length, 1 inch (2.54 cm) diameter, made from polyethylene hose. The mainline was connected with the three water tanks by control valves. Sub-main line was connected to the lateral lines with 9 connectors and also raised about 1 m high above the ground. The lateral lines were made of black low density polyethylene (L.D.P.E) of 13 mm diameter and 6 m length. The distance between adjacent lines consecutive was 10 cm. Each consisting of 10 emitters were spaced 5 cm, 90 cans replicated three times (Figure.1). And also was used Agri –Meter device, for testing salinity of water. (Conductivity range 0 -5 deciSiemens per metre (dS/m)).

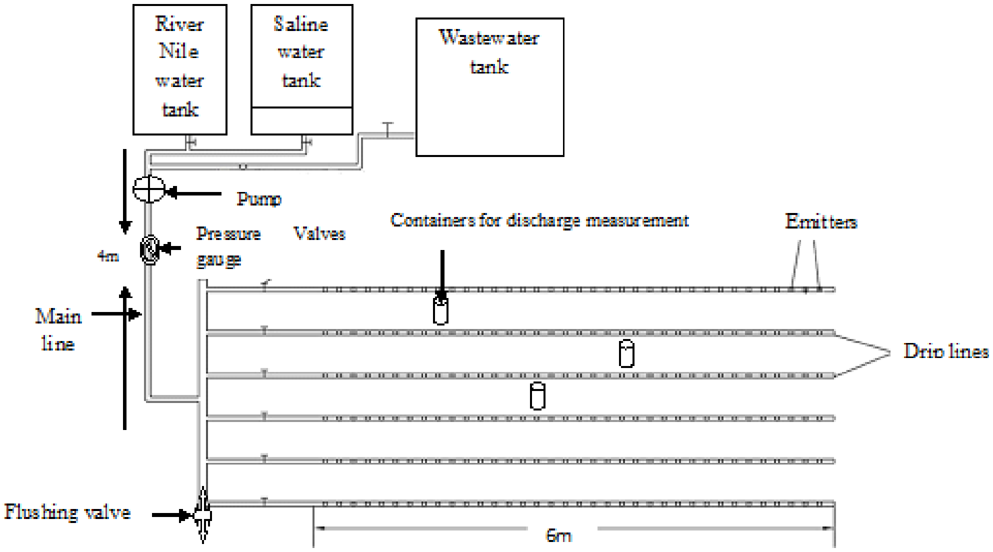

Figure 1. Layout of the experimental model

Hydraulics of Drip irrigation system and drip emitter theory

Hydraulics of emitters

The most important factor to the success or failure of drip irrigation system is the hydraulic design. According to Hillel (1987), the discharge for most drip irrigation can be given by Equation 1 :

$$Q = K_d \times H^x \quad \text{……………………………………………………(1)}$$

Where "Q" is emitter flow rate discharge (Lh-1), "Kd" is discharge coefficient, "H" is pressure head at the emitter, "x" is emitter discharge exponent.

Uniformity of water application by drip irrigation system is a main concept that affects the design and operation of the system. The emission uniformity (EU %) was computed using the Equation 1 (ASAE, 1994):

$$EU = 100\left(1 - \frac{1.27cv}{\sqrt{n}}\right)\frac{q_n}{q_{ave}} \quad \text{……………………….…….………..(2)}$$

Where (EU), is emission of uniformity (%), (q_n), is average rate of discharge of the lowest one-fourth of the emitters discharge readings (Lhr^{-1}), (q_{ave}), is average discharge rate of all the emitters checked (Lhr^{-1}), (n) is number of observation, (Cv), is coefficient of variation, has been calculated by Equation 2 (ASAE,2002).

$$Cv = \frac{S}{\bar{X}} \quad \text{……………………………………………………….…………(3)}$$

Where (Cv) is manufacturing variation coefficient,($\overline{x}$) is described as the average flow of emitters, "S" is as standard deviation. The (S) value given in Equation 2 has been calculated by Equation 3.

$$S = \left[\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}\right]^{\frac{1}{2}} \text{………………………………………………….……..(4)}$$

Where (x_i) is the emitter flow (l/h) and (n) is the number of emitters.

Was obtained the overall application efficiency of drip irrigation (Ea) by Vermeiren and Gobling, (1990) as follows:

$$Ea\% = Ks \times Eu \quad \text{…………………………….………………………….……… …… (5)}$$

Where Ea is application efficiency (%), Ks is ratio between water stored and that diverted from the source, Eu is emission uniformity (%).

The Christiansen coefficient uniformity (CU %) is calculated by Equation 5. the obtained results have been assessed by consider the circumstance of CU ≥ 97.5 when the distinction between the highest and lowest emitter flows is 10% (Yildirim and Apaydin, 1999; Korukcu, 1980).

$$CU = 100\left(1 - \frac{\Delta q_0}{q_0}\right) \quad \text{. . ……………………………….….……... (6)}$$

Where "CU" is defined as Christiansen's uniformity coefficient (%), Δq_0 is as amean absolute deviation of the average of each emitter (Lhr^{-1}) or lateral inlet flow, "q_0" is the average emitters.

The percentage of clogged emitters (P_{clog}%) is determined using the Equation 6 as stated by Liu and Huang (2009):

$$P_{clog\%} = 100\left[\frac{Nes_{clog}}{Nes_{total}}\right] \quad \text{……………………………... (7)}$$

Where "P_{clog}"is percentage of clogging (%), "Nes_{clog}" is number of clogged emitters, "Nes_{total}" is total number of emitters.

Statistical Analyses:

Statistical Analysis among treatments was determined by Analysis of Variance (ANOVA) for Completely Randomized Designs (CRD) and LSD at a significant level of ($P < 0.05$) in the Minitab V.13Edition computer software.

RESULTS AND DISCUSSION

1. Means of emitters Discharge rate (L h^{-1})

Table .1 and Fig .2 show there were no significant differences ($P \geq 0.05$) among emitters and there were significant differences ($P \leq 0.05$) among water qualities. The average discharge rate for the emitter type pressure compensating –Black online was higher for raw river Nile water 0.20 dS/m of salinity (RRNW) followed by well water 0.35 dS/m of salinity (WWS), saline water 5.0 dS/m of salinity (SW2), saline water 3.5 dS/m of salinity (SW1) and Treated wastewater 5.75 dS/m of salinity

(TWWS), respectively. As for the emitter type pressure compensating blue online discharge rate for WWS, RRNW was more than double the discharge rate of the other types of water, which were more or less similar to each other with regard to the emitter type Inline, the discharge rate was the same in WWS and TWWS, whereas, discharge rate of SW1 and RRNW was comparable and the lowest discharge rate was in SW2 (Table .1 and Fig .2).This result may be due to the fact that inline emitter type is sensitive to clogging whereas the Blue online emitter needs more than 2 bar pressure for better performance. These results are supported by Nacayama and Bucks, (1991).

Table 1. means of emitters Discharge rate (L h^{-1})

Type of water (Salinity levels)	Type of emitter			Means
	Black	Blue	Inline	(L h^{-1})
RRNW	3	3	2	3^{a}
WW S	3	3	1	2^{b}
SW1	2	2	2	2^{b}
SW2	2	1	1	1^{c}
TWWS	1	1	1	1^{c}
Means	2^{b}	2^{a}	1^{b}	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

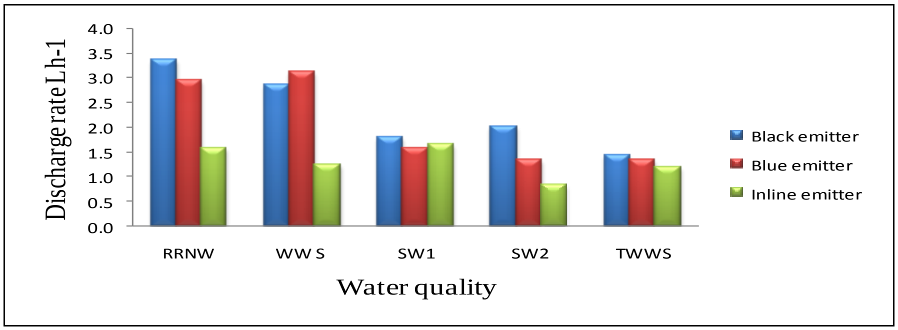

Figure 2. means of emitters discharge rate Lh^{-1}

Where: RRNW is Raw River Nile water 0.20 dS/m of salinity, WWS is Well water 0.35 dS/m of salinity, SW1is Saline water 3.5 dS/m of salinity, SW2: Saline water 5.0 dS/m of salinity, TWWS is Treated wastewater 5.75 dS/m of salinity**.**

2. Reductions (R %) in emitters discharge

As shown in Table .2 and Fig .3 there were significant differences ($P \leq 0.05$) among treatments. Whereas the greater reduction in emitter type Inline was found in SW1 followed by WWS and SW2. On the other hand, RRNW and TWWS showed the least reduction hence they are considered as having the best reduction in discharge rate as compared to the other treatments. In case of the emitter type Blue online, the greatest reduction in discharge rate was found in TWWS, SW1, followed by WWS and SW2, respectively. The highest discharge rate recorded for RRNW can be attributed to the very low amount of reduction %. Interestingly for emitter type Black online, SW1 had the least reduction % and consequently the highest discharge rate. The lowest discharge rate was found for TWWS because of a very high reduction % as compared to all treatments. This result may be due to the fact that compensating emitter type Blue online has higher discharge rate than the others. These results are in accordance with the findings of Nakayama and Bucks (1991).

Table 2. Reductions (R %) in mean discharge

Type of water (Salinity levels)	Type of emitter			Means
	Black	Blue	Inline	(%)
RRNW	0.22	0.022	0.19	0.14^{c}
WW S	0.16	0.28	0.59	0.34^{a}
SW1	0.044	0.39	0.63	0.35^{a}
SW2	0.16	0.12	0.57	0.28^{b}
TWWS	0.38	0.51	0.2	0.36^{a}
Means	0.19^{c}	0.26^{b}	0.44^{a}	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

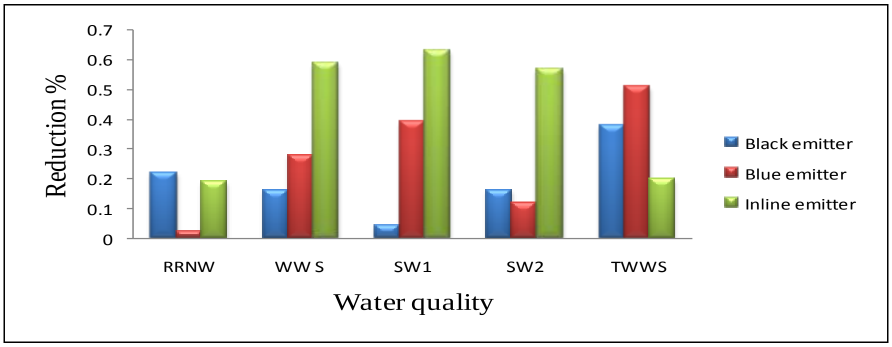

Figure 3. Reductions (R %) in emitters discharge

3. *Coefficient of variation (CV %)*

Water treatments and emitter types both showed positive effects on the coefficient of variation (CV). Whereas WWS under emitter type Blue online revealed highest significant differences ($P \leq 0.05$) followed by both SW1, SW2 under emitter type Black online and Inline emitter, respectively (Table.3 and Fig.4). These results may be due to that the Well water has higher levels of impurities than the other water quality. This result is in an agreement the findings with Nakayama and Bucks (1991) and Bralts (1986).

Table 3. Coefficient of variation (CV) of emitters discharge

Type of water (Salinity levels)	Type of emitter			Means (%)
	Black	Blue	Inline	
RRNW	0.17	0.18	0.18	0.18^{c}
WW S	0.21	0.39	0.30	0.30^{a}
SW1	0.13	0.21	0.27	0.20^{c}
SW2	0.18	0.21	0.20	0.20^{c}
TWWS	0.26	0.21	0.26	0.24^{b}
Means	0.19^{c}	0.24^{b}	0.24^{b}	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

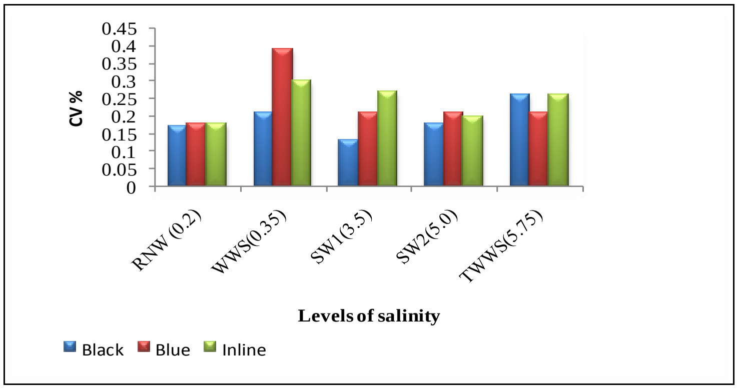

Figure 4. Coefficient of variation (CV) of emitters discharge

4. *Christiansen coefficient of uniformity (CU %) of emitters discharge*

The RRNW had significantly ($P \leq 0.05$) lower mean coefficient of uniformity as compared to all other types of water (Table.4 and Fig.5). The WWS led to the highest mean of CU% followed by SW2 TWWS and SW1, (Table.4 and Fig.5). In case of the emitters the highest values of CU% were recorded by emitter type Black online with water qualities WWS and SW1, whereas the emitter type Blue online with water type RRNW recorded the least CU% and the emitter type Inline SW1recorded the lowest CU% (Table.4 and Fig.5). This result agrees with the findings of Osman (2002).

Table 4. Christiansen coefficient of uniformity (CU) of emitters discharge

Type of water (Salinity levels)	Type of emitter			Means (%)
	Black	Blue	Inline	
RRNW	84	72	76	77^{c}
WW S	87	82	82	84^{a}
SW1	87	78	72	79^{b}
SW2	81	78	79	80^{b}
TWWS	80	84	78	80^{b}
Means	84^{a}	79^{b}	77^{c}	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

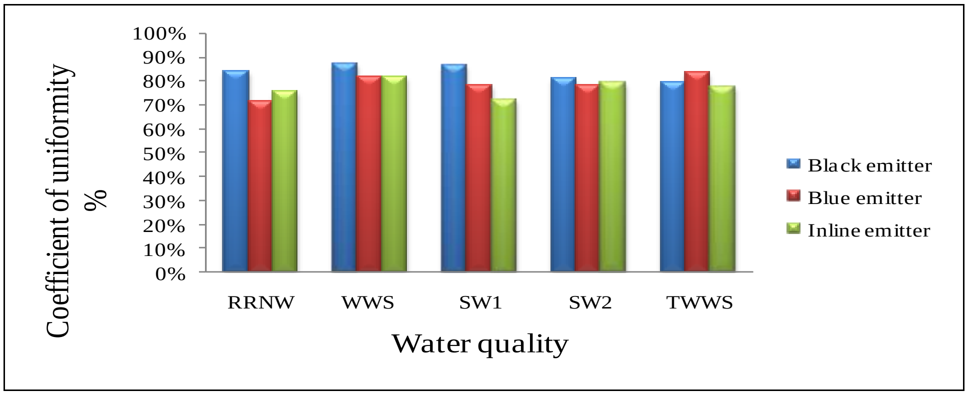

Figure 5. Coefficient of Uniformity (CU %) of emitters discharge

5. *Emission uniformity (EU %) of emitters discharge*

Analysis of variation showed that there were significant differences ($P \leq 0.05$) among treatments. The highest values of emission uniformity (EU %) were recorded with WWS, followed by SW2, TWWS, SW1 and RRNW, respectively (Table.5 and Fig.6). With regard to emitters, the emitter type pressure compensating. Black online showed the highest mean values of emission uniformity across the different types of water qualities as compared to the other emitter types, followed by the Inline emitter type whereas the Blue online emitter recorded the least mean value of emission uniformity (Table.5 and Fig.6).This result may be due to clogging especially for pressure compensating emitters where the flexible membrane of the emitter may have lost its elasticity over time due to deposits of mud and silt and some chemical materials. These findings are in line with those of Elham (2012).

Table 5. Emission uniformity (EU %) of emitters discharge

Type of water (Salinity levels)	Type of emitter			Means (%)
	Black	Blue	Inline	
RRNW	72	40	60	57^{c}
WW S	78	64	72	71^{a}
SW1	79	59	58	65^{b}
SW2	71	71	69	70^{a}
TWWS	66	72	64	67^{b}
Means	73^{a}	61^{c}	65^{b}	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

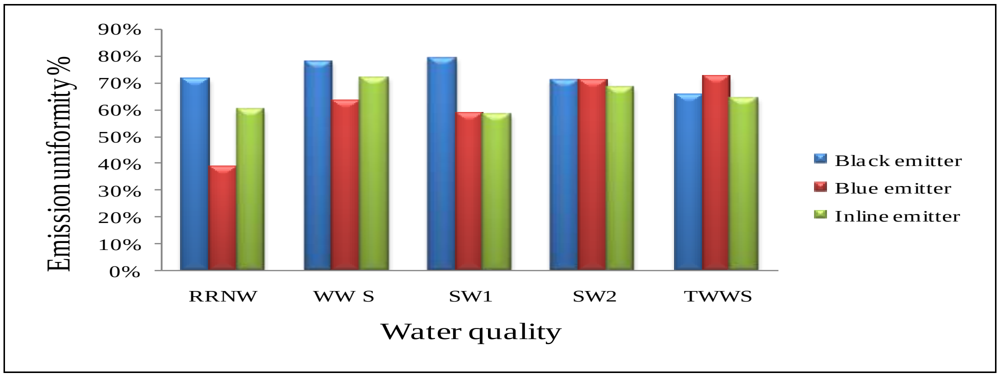

Figure 6. Emission uniformity (EU %) of emitters discharge

6. Scheduling uniformity (SU) of emitters discharge

As presented in Table .6 and Fig .7 there were no significant differences at the level $P \leq 0.05$ among treatments. The highest value of SU was recorded by RRNW, WWS and SW1 under Black and Inline emitter respectively. However, the SU followed the same trend of DU% as being affected by the same factors that affected DU%. This result agrees with the findings of Ravina (1992).

Table 6. Scheduling uniformity (SU) of emitters discharge

Type of water (Salinity levels)	Type of emitter			Means
	Black	Blue	Inline	
RRNW	0.02	0.01	0.01	0.02^a
WW S	0.01	0.01	0.02	0.02^a
SW1	0.02	0.02	0.01	0.02^a
SW2	0.01	0.01	0.01	0.01^b
TWWS	0.01	0.01	0.01	0.01^b
Means	0.01^b	0.01^b	0.02^a	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

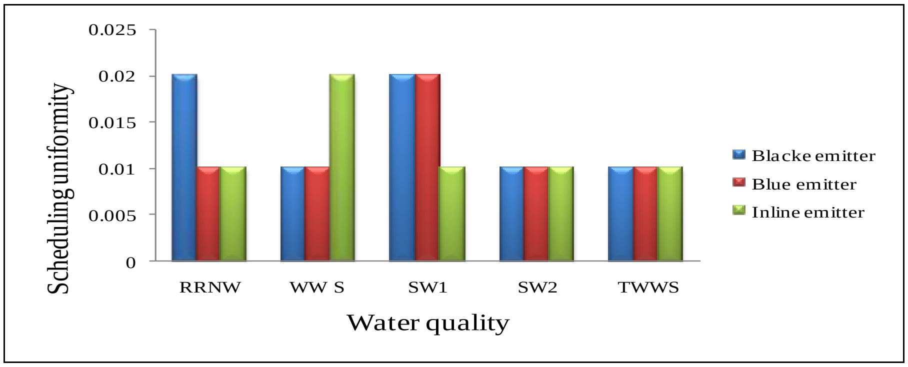

Figure 7. scheduling uniformity (SU) of emitters discharge

7. Application efficiency (EA) of emitters discharge

As shown in Table .7 and Fig .8 there was significant difference ($P \leq 0.05$) in EA among treatments. Where SW1 and WWS recorded the highest values of (75%), (74%) respectively with emitter type Black pressure compensating while the lowest value of (37%) was recorded by emitter type Blue pressure compensating when using water quality RRNW. These results may be attributed to the fact that saline water and well water have lowest the content of solid materials and clay. Hence, it can be stated that in general when the clogging percentage is very low, this will lead to high application efficiency. This result is confirmed by Scicolone (1998).

Table 7. Application efficiency (EA) of emitters discharge

Type of water	Type of emitter			
	Black	Blue	Inline	Means (%)
RRNW	55	36	65	52 ^{c}
WW S	65	55	69	63 ^{a}
SW1	54	53	71	59 ^{b}
SW2	62	64	64	64 ^{a}
TWWS	57	65	59	60 ^{b}
Means	59 ^{b}	55 ^{c}	65 ^{a}	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

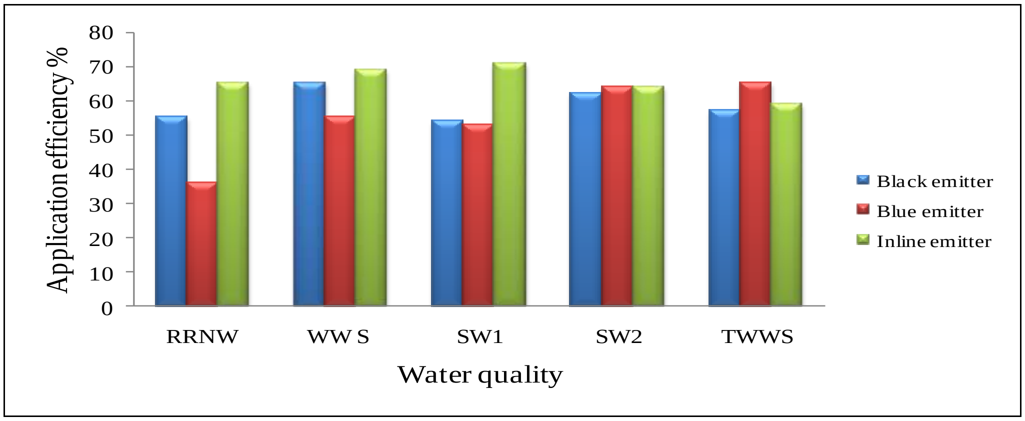

Figure 8. Application efficiency (EA) of emitters discharge

8. Percentage of completely clogged ($P_{clog\%}$) emitters

The conditions of completely clogged emitters are shown in Table .8 and Fig.9. The blue online emitter with SW2 revealed significant difference ($P \leq 0.05$) as compared with the other treatments (Table.8 and Fig.9). On the other hand, the water quality TWWS showed no clogging ($P_{clog\%}$) with emitters type Black, Inline followed by water qualities WWS (1.1%), RRNW (1.1%), SW1 (2.2%) and SW2 (3.3%) respectively. These results agree with the findings of Capra and Scicolone (1998) who stated that the clogging percentage varied due to emitter type and water quality.

Table .8 Percentage of completely clogged ($P_{clog\%}$) emitters

Type of water (Salinity levels)	Type of emitter			
	Black	Blue	Inline	Means (%)
RRNW	0	3.0	0	1.1^{c}
WW S	0	3.0	0	1.1^{c}
SW1	0	6.7	0	2.2^{b}
SW2	0	10.0	0	3.3^{a}
TWWS	0	0.0	0	0.0^{d}
Means	0^{b}	5.0^{a}	0^{b}	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

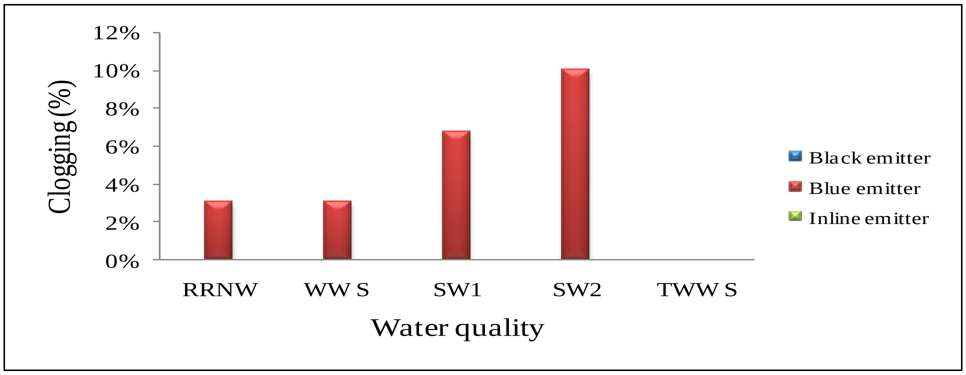

Figure 9. Percentage of completely clogged ($P_{clog\%}$) emitters

9. *Percentage of partially clogged ($P_{clog\%}$) emitters*

The emitter types differenced significantly in ($P \leq 0.05$) percentage of partial clogging. The black emitter showed significantly the least clogging, followed by Blue emitter and the highest percentage of clogging of about 85% was found in the inline emitter (Table .9 and Fig .10). With regard to the types of waters SW2 and TWWS showed significantly higher clogging percentage. Significantly least clogging was found for the RRNW followed by SW1 which also showed significantly least ($P \leq 0.05$) clogging percentage then WWS (Table .9 and Fig .10).

Table 9. Percentage of partially clogged ($P_{clog\%}$) emitters

Type of water (Salinity levels)	Type of emitter			
	Black	Blue	Inline	Means (%)
RRNW	7	37	23	22 ^{d}
WW S	47	43	97	62 ^{b}
SW1	20	53	70	48 ^{c}
SW2	13	77	130	73 ^{a}
TWWS	53	57	107	72 ^{a}
Means	28 ^{c}	53^{b}	85 ^{a}	
LSD	2.28	2.43	0.56	

Means with same letter are not significant difference at $P \leq 0.05$

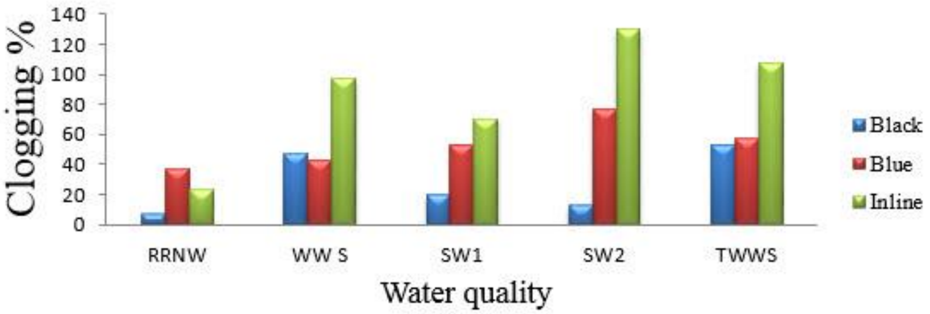

Figure 10. Percentage of partially clogged ($P_{clog\%}$) emitters

CONCLUSION

From the results of this study the following conclusions are drawn; Drip Irrigation system can be used cautiously with highly saline water, The inline types of emitters give both hydraulic performances with highly saline irrigation water, Effect filtration process a required with any type of emitters when treated wastewater is recycled for irrigation by drip system.

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