A Study of Emitter Clogging and Development of the Mathematical Relationship between Emitter Clogging and Water Quality

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Abstract: The performance of the drip irrigation system and its water application could be degrading at a high level by the clogging. Emitter clogging a function of the water quality, included: suspended solids, chemical component and biological activities.
In the current study, causes of emitter clogging in the some different systems were investigated. To achieve this aim water quality testing was performed and the results were compared with the standard criteria to evaluate the clogging potential. Also effects of emitter performance variation on the water application uniformity evaluated involved the ASAE EP458 standards. Finally, for the drip irrigation systems which were studied, the mathematical regression equation between emitter clogging and water quality was developed.

Keywords: emitter clogging, field evaluation, water quality, regression equation.

Introduction

Drip irrigation systems are methods of water distribution which delivers water and nutrients to precise amounts and controlled frequencies directly to the plants root one via pressurized network.
Micro irrigation systems have many potential advantages when compared with other irrigation methods. Most of them are related to the low rates of water application. It can be argued that some of these benefits are not unique to a micro irrigation system. However, certain combinations of these advantages are responsible for uniqueness of micro irrigation in contrast to other systems (Haman, Izuno 1989).
Micro irrigation, properly managed, offers several potential advantages over other methods of irrigation. The clogging of emitters is one of the most serious problems associated with micro irrigation use. Emitter clogging can severely hamper water application uniformity (Pitts, et al 2003).
Information concerning emitter discharge rates and uniformity has been presented by several researchers. Bralts et al (1981) an attempt to statistically include manufacturing variation in calculations for uniformity and emitter flow variation of single chamber and emitter clogging in the calculations for uniformity of single and dual chamber drip irrigation lateral lines. A simulation model was developed by Nakayama and Bucks (1981) to evaluate the uniformity and average water discharge rate of a trickle system with different degrees of clogging. Bralts and Kesner (1983) presented a statistical

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method for field uniformity estimation of drip irrigation sub main units based upon the coefficient of variation and statistical uniformity coefficient. Solomon (1985) was developed a simulation model which treats the various equipment, system and other factors known to influence emitter flow rate variation. Talozi and Hills (2001) was developed a mathematical model to simulate the effects of emitter clogging on subunits hydraulics.

Gilbert et al (1979) experiments using Colorado River irrigation water on citrus trees in south western Arizona were conducted to evaluate clogging of emitters and to investigate methods for controlling clogging. Bucks et al. (1979) compiled a water quality classification relative to its potential for drip emitter clogging.

Clogging hazards for drip irrigation systems fall into three general categories: physical (sediment), biological or organic (bacteria and algae), and chemical (scale). Frequently, clogging is caused by a combination of these factors. The type of emitter clogging problems will vary with the source of the irrigation water. Water sources can be grouped into two categories: surface and ground water. Each of these water sources is likely to present specific clogging hazards (Benham and Blake Ross, 2002).

Irrigation water testing is performed to evaluate the suitability of a water source for use with drip irrigation systems. Testing can also be used after emitter clogging problems arise to determine the source of clogging and to devise a plan to correct the problem (Storlie, 1995).

The review of selected studied on uniformity and emitter clogging shows no study addresses mathematical relationship between emitter clogging and water quality. The objectives of the present work are: (a) to introduce the notion of ASAE EP458 capability to emitter clogging evaluation; (b) the effect of the most chemical composition on water application uniformity (c) developed mathematical relationship between emitter clogging and water quality.

Methodology

1- Drip irrigation water Test

Fourteen systems were visited. Seven systems with chemical clogging and suitable data are used. Table (1) shows the characteristic these systems.

Table 1. General characteristic of seven suitable systems

System No.	Namely discharge (lit/hr)	Emitter type	Tree crop	Number of emitter per tree
1	4	In-line	Citrus	6
2	4	In-line	Peach & Plum	4
3	4	In-line	Peach & Plum	4
4	4	In-line	Olive	1
5	4	In-line	Pomegranate	3
6	4	In-line	Olive	1
7	4	In-line	Pistachio	1

The water for the experiment was taken from the emitter emission water and delivered the samples to a testing lab, and interpreting the water analysis. Since chemical properties of the irrigation water (pH) and chemical constituents (iron, manganese, hardness) can cause chemical reactions and result in the precipitation of certain water and fertilizer constituents, we performed these tests in a capable water testing laboratory. The results are shown in Table (2).

Table 2 Irrigation water test in visited system

System No.	SAR	concentration (ppm)				concentration (meq/l)						PH	EC 10^6
		hardness	TDS	Mn	Fe	Na	Mg	Ca	Cl	HCO_3	CO_3		
1	0.5	268	312	0.02	0	0.9	2.5	2.9	0.3	5.2	0	7.4	488
2	1.5	313	492	0.02	0.04	2.5	2.4	3.9	7.6	4.8	0	7.3	769
3	0.3	308	326	0	0.04	0.5	2.5	3.7	2.5	4.6	0	7.3	510
4	0.4	407	451	0.01	0	0.7	4.3	3.9	1.4	5.4	0	6.7	705
5	4.6	2040	2923	0.02	0	21	12	29	17	2.8	0	6.3	4568
6	4.9	1940	3029	0.02	0	21.5	13	26	19	3.2	0	7.8	4734
7	10.1	1990	4970	0.02	0.03	45	12	28	53	2.4	0	6.5	7766

2- Field evaluation of drip irrigation systems

Using the Field Uniformity Estimator, as few as 18 flow measurements per zone can provide a reasonable estimate of actual water flow uniformity in a good drip irrigation system. Measurements were taken only after the system has reached its normal operating pressure and flow rate. These measurements were scattered uniformly over the zone to be tested to accurately represent conditions throughout the entire zone. Individual emitters were randomly selected. For accuracy, the water caught measured in milliliters. A graduated cylinder marked in milliliters used to measure volume caught. For each selected emitter 200 milliliters water caught. A wrist watch with a seconds indicator did the timing. Therefore ASAE EP458 methods used to evaluate drip irrigation systems as follows:

2-1- Flow Rate Variation and Uniformity

The uniformity of water application can be calculated from the statistical distribution of emitter flow rates that are measured in the field.

$$U_s = 100\,\%(1-V_{qs}) \qquad (1)$$

Where

U_s = statistical uniformity of the emitter discharge rates, and V qs = statistical coefficient of variation of emitter discharge rates.

In Equation (1), the coefficient of variation is the standard statistical definition of the sample standard deviation divided by the mean.

2-2- Pressure Variation and Uniformity

Hydraulic uniformity refers to the effects of pressure variation on the uniformity of water application from a drip irrigation system. Hydraulic uniformity, Ush , is defined similar to water application uniformity in Equation (1) , except that the emitter discharge exponent, x, must also be considered. This exponent shows the relationship between emitter operating pressure and flow rate. Because x is different for different types of emitters, the allowable pressure variation is also different for each emitter type.

$$Ush = 100\ \%(1-xVhs) \qquad (2)$$

Where

U sh = hydraulic uniformity based on pressure distributions,

x= emission exponent, and

Vhs= hydraulic variation, which is the statistical coefficient of variation of pressures.

In this study pressures easily measured using a portable pressure gauge at the same emitters where flows were measured.

-Emitter flow equation determination

The relationship between emitter operating pressure and flow rate given by:

$$q_e=KH^{X} \qquad (3)$$

Where:

q_e= emitter flow rate, K= emitter discharge coefficient, H= operating pressure and x emission exponent.

In this study, the coefficient (K) and exponent (X) for this equation from testing laboratory obtained is as below:

In different pressure condition at 0.2, 0.4, 0.6, 0.8, 1 bar, the average of 4 emitter flow rate in lit/hr measured. Then by power regression type between q and H emitter flow rate equation with R^2=0.98 is obtained as below:

$$q=1.61H^{0.44}$$

The above equation shows that the exponent X=0.44, in in-line emitter which is under study is a turbulent flow emitter.

2-3- Emitter Performance Variation and Uniformity

Emitter performance variation, V_{pf} refers to non-uniformity in water application that is caused by the emitters. If the emitter performance variation is high, this is normally due to emitter clogging or to manufacturing variation among emitters. It may also be due to other factors which affect emitter flow rates, such as temperature. The emitter performance coefficient of variation, V_{pf}, shall be determined using the equation as follows:

$$V_{pf} = (V_{qs}^2-V_{qh}^2)^{1/2} \qquad (4)$$

Where

V_{qs} = emitter discharge coefficient of variation

V_{qh} = emitter discharge coefficient of variation due to hydraulic

The statistical uniformity of the emitter performance, U_{pf}, is determined as follows:

$$U_{pf} = 100(1-V_{pf}) \qquad (5)$$

3- Mathematical relationship development

To develop the mathematical relationship, various water quality parameters were studied. Finally, the PH, temporary hardness and dissolved solids as independent variables were considered. Therefore Emitter Performance Variation was used as a dependent Variable. The multi variable of nonlinear regression can be performed, using suitable software such as Data Fit by which 90 different models were run.

Result and Discussion

Water Quality evaluation

Fourteen visited systems were mainly wells and all of the systems were equipped with filtration units. In the most of visited systems the filters especially screen filters was frequently flushed. This flushing was down on a set time interval or at a specific pressure drop. Therefore the main of causes of emitter clogging were chemical agents. Table 3 shows chemical water quality testing was compared with the standard criteria to evaluate to evaluate the clogging potential.

Table 3. Chemical water quality testing evaluation

System no.	hardness	clogging potential	TDS	clogging potential	Mn	clogging potential	Fe	clogging potential	PH	clogging potential
1	268	moderate	312	Slight	0.02	Slight	0	Slight	7.4	moderate
2	313	severe	492	Slight	0.02	Slight	0.04	Slight	7.3	moderate
3	308	severe	326	Slight	0	Slight	0.04	Slight	7.3	moderate
4	407	severe	451	Slight	0.01	Slight	0	Slight	6.7	Slight
5	2040	severe	2923	severe	0.02	Slight	0	Slight	6.3	Slight
6	1940	severe	3029	severe	0.02	Slight	0	Slight	7.8	Severe
7	1990	severe	4970	severe	0.02	Slight	0.03	Slight	6.5	Slight

Physical and biological clogging in some system occurs and the there was because:

1- lake of adequate management
2- Ignorance of farmers from operation functions of filtration and flushing.
3- Biological (bacterial and algae) in sedimentary basin
4- Lake of sediment basin installation
5- Sedimentation of suspended particle in systems due to low pressure

In some systems, water quality test shows that amount of suspended solid in water is very low and can be ignored. The result shows that the main cause of clogging was temporary hardness.

In some systems, the white and tiny layers of calcium carbonate on the emitters and soil were appeared. In these systems the ignorance of chemical treatment causes to clogging accumulation and only in one system acid treating causes to improve emitter performance. In most system, there was fertilizer tank with filtration system. But it was rarely used for fertigation and chemical injection. Systems assessment indicated that many of them with problem such as low quality components, low designing and low management that cause decline in system efficiency and performance.

Water Application uniformity evaluation

In the visited system statistical uniformity (U_s) based on emitter discharge rates, hydraulic uniformity (U_{sh}) based on pressure distributions and statistical uniformity of the emitter performance (U_{pf}) is classified as shown in Table 4, and 6.

Table 4 U_s evaluation

System No.	V_{qs}	U_s	**classification**
1	0.08	92	Excellent
2	0.16	84	Very good
3	0.25	75	Fair
4	0.07	93	Excellent
5	0.28	72	Fair
6	0.20	80	Very good
7	0.12	88	Very good

Table 5 V_{hs} evaluation

System No.	V_{hs}	V_{qh}	U_{sh}	**classification**
1	0.09	0.04	96	Excellent
2	0.22	0.1	90	Fair
3	0.28	0.12	88	Fair
4	0.14	0.06	94	Very good
5	0.28	0.12	88	Fair
6	0.07	0.03	97	Excellent
7	0.06	0.03	97	Excellent

Table 6 V_{pf} evaluation

System No.	V_{pf}	U_s	**classification**
1	0.07	93	Excellent
2	0.12	88	Very good
3	0.21	79	Fair
4	0.04	96	Excellent
5	0.25	75	Fair
6	0.20	80	Fair
7	0.12	88	Very good

According to Table 4 to 6 the following result:

- Whenever U_s is excellent, U_{sh} and V_{pf} is excellent.
- Whenever U_s is very good, V_{pf} is very good or fair.
- Whenever U_s is fair, U_{sh} and V_{pf} is fair.

Therefore we can say Vpf more effective than Ush in declining of Us. Figure (1) indicate that descending of clogging or Vpf.

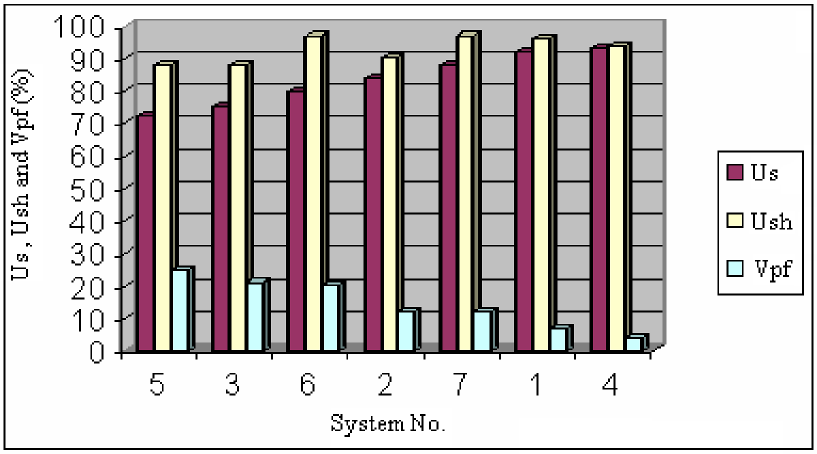

Figure (1) shows that V_{pf} have inverse relationship to U_s but is not effective to U_{sh}.

Mathematical relationship evaluation

One of the advantages of development of mathematical relationship in comparison to "criteria for plugging potential of micro irrigation water sources (Bucks and Nakayama Table)" is assessment of effects of Interactive water quality factors. For example, there may be a kind of water which is with pH or hardness near to "Slight" or between "moderate" and "Severe" in Table will not cause emitter clogging (but in fact, there are much probability for this water to create severe problem for the system).

Instead of water which have very high acidity and have little hardness, as it has shown in the Table causes "severe" emitter clogging (it has much probability this water has less problems for the system).

To develop a mathematical relationship in first stage, acidity, total hardness and dissolved solids as independent variable were considered. Due to, low concentration of Fe and Mn, these elements were not considered. In this stage regression coefficient between these factors and V_{pf} (dependent variable) was low.

In second stage, acidity, permanent hardness and dissolved solids were considered as independent variable. But still regression coefficient was low.

In the third stage, acidity, temporary hardness and dissolved solids were considered as independent variable. In this stage regression coefficient was good and it was equal to 0.985. There fore non-linear multi regression was obtained as follow:

$$Y = \exp(ax_1 + bx_2 + cx_3 + d)$$

Where:

Y= emitter performance variation

x_1= acidity

x_2= temporary hardness

x_3=dissolved solids.

a, b, c and equals 0.281,-0.028,-0.008 and 7.650 respectively.

In the above a, b, c and d equation coefficients and may be alter in other systems with different water quality and emitters.

In fact, temporary hardness indicator of precipitation of calcium carbonate in the water. We can say the factors in the above equation the highest effects in emitter clogging and from this view point above equation complies with national condition.

Table (7) and figure (2) show calculated clogging error in above equation in different visited system.

Table (7) error for mathematical relationship between emitter clogging and water quality

X_1 (pH)	X_2 (temporary hardness)	X_3 (dissolved solids)	Y (visited clogging)	Y (calculated clogging)	Residual	Error%	Absolute residual
7.4	260	312	7	8.491	-1.491	-20.988	1.491
7.3	240	492	12	12.655	-0.655	-5.458	0.655
7.3	230	326	21	19.036	1.964	9.353	1.964
6.7	270	451	4	4.722	-0.722	-18.043	0.722
6.3	140	2923	25	25.764	-0.764	-3.055	0.764
7.8	160	3029	20	20.574	-0.574	-2.868	0.574
6.5	120	4970	12	10.216	1.784	14.865	1.784

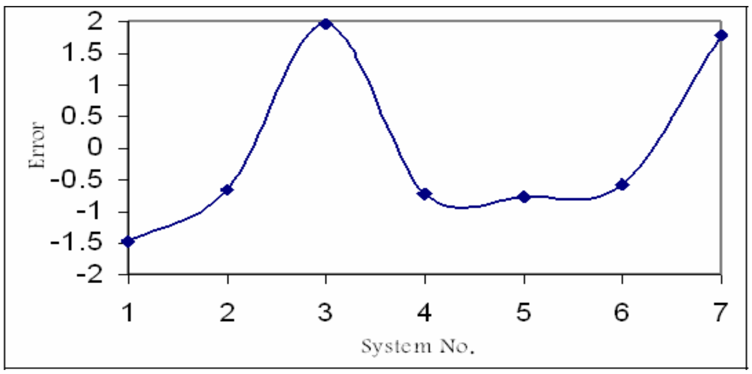

Figure 2 calculated clogging error in mathematical relationship between emitter clogging and water quality

Conclusion

One of the most important factors of proper performance in drip irrigation is good maintenance and management. In visited systems when ever clogging problem was low, it was due to lake of awareness of the user from technical information of filtration operation and flushing procedure. It is necessary for farmers to have a manual which provide information about irrigation time and interval, flushing of system network and filters and number of sub main to be simultaneously irrigated.

It is advisable to use emitter with high emitter operating pressure in the area which has water hardness and high concentration of substances. We should consider choose emitter not only match crop water requirement but also it should survey clogging potential.

It is proposed that water application uniformity tests as a guarantee of performance for the companies which undertake to install drip irrigation systems. Also, we can consider by frequent these tests to study system performance in consecution years. By execution of this procedure we can remove the shortcoming and defects of the system. Moreover we can study special emitter performance related to water quality in specific area over a period of time.

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