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The Effects of Fertigation Management in the Different Type of In-line Emitters on Trickle Irrigation System Performance

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Abstract: This study was carried out to determine the effects of different fertigation practices on irrigation system performance in in-line emitters using Samandağ region well water. The experiment was conducted at the research field of the Samandağ Vocational College, University of Mustafa Kemal, Hatay, from 2001 to 2002. In the experiment, three different emitters (1.7, 2.75 and 4.0 L h^{-1}), three different fertilizer treatments (no-fertilizer, hju MKP+$Ca(NO_3)_2$+KNO_3+KSO_4+NH_4NO_3 and NH_4NO_3+KSO_4+MKP) combinations with flushing and no flushing management groups were tested in three replications. Emitter discharge rates were tested at the beginning and end of every season to determine emitter flow variations. The effect of the different fertilizer treatments on system performances was found to be statistically significant. Fertilizers which included both calcium and sulfates resulted in lower system performance than the others. Emitters that have the lowest flow rates had the lowest performance. The acid treatment and flushing management increased the system performance slightly, but it was found not to be statistically significant.

Key words: Drip irrigation, fertigation, irrigation uniformity, system performance

INTRODUCTION

Drip irrigation method provides plant water requirement more regularly and frequently when compared to the other irrigation methods (Özekici and Sneed, 1995). It has important advantages over other irrigation methods; nutrients and other chemicals could be applied with water more frequently and regularly as needed by plants, which result in more healthier and higher yielding plants (Nakayama and Bucks, 1981).

Efficiency of drip irrigation system depends on uniformity of water coming from all emitters of the system. Any alteration of emitter discharge rates can result in lower application uniformity than expected. Clogging of drip-lines results in a significant decrease in both the average emitter discharge and the distribution uniformity, such that these fall below the acceptable ranges identified earlier (Marcu *et al.*, 1992).

In a growing season, the highest irrigation efficiency is only possible with a good planning and management (Smajstrla *et al.*, 1990). System uniformity can be lower due to equipments defects such as valves and pressure regulators and clogging of emitters (Hochmuth and Smajstrla, 1991).

Emission uniformity of a drip irrigation system should be tested regularly by measuring emitter discharge rate and calculating efficiency value of the system. When fertigation is preferred the emission uniformity should be 95% or higher (Smajstrla *et al.*, 1990).

The clogging of drip emitters is the largest maintenance problem with drip systems (Keller and Bliesner, 1990). It is difficult to detect and expensive to clean, or replace, clogged emitters. Partial or complete clogging reduces emission uniformity and as a consequence, decreases irrigation efficiency (Capra and Scicolone, 2004).

Quality of irrigation water also effects the degree of emitter clogging (Bucks *et al.*, 1979). High concentrations of soluble salts in the water is the most important factor of clogging. Hills *et al.* (1989) examined the four management schemes and three water qualities with electrical conductivities of 0.59, 1.12 and 2.02 dS m^{-1} for lessening the chemical clogging effects of high calcium content water in drip-tape. Results showed that partial and full clogging due to chemical precipitation occurred in all management schemes for the water with the highest salt content. Flow values in the laterals had decreased between 20 and 40% for this water. Corresponding flow

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reduction for the lowest salt content water varied between 3 and 15%. Of the management modes evaluated, reduction of water pH from 7.6 to 6.8, by sulfuric acid injection provided the least clogging for all three water qualities.

The most important disadvantage of fertigation is precipitation of chemical materials and clogging of emitters (Papadopoulos, 1993). In some cases, a combination of carbonate precipitates and fertilizers are responsible for severe clogging of drip irrigation systems (Sagi, 1990).

Hebbar *et al.* (2004) were declared that, in fertigation, use of 100% water-soluble fertilizer is recognized to safe guard the drip system in a long run. The normal fertilizer generally tends to clog the emitters and cause uneven distribution of fertilizers. However, in the study of 2 years, no clogging of emitters was observed.

An experimental trials carried out on the behaviour of six kinds of filters (gravel media, disk and screen) and four types of drip emitters (vortex and labyrinth) using five kinds of municipal wastewater that have not undergone previous advanced treatment. Results showed that of the emitters with a similar discharge, vortex emitters were more sensitive to clogging than labyrinth emitters. In-line labyrinth emitters in pipes with a smaller diameter were more sensitive to clogging than the same kind of emitter in pipes with a greater diameter (Capra and Scicolone, 2004).

Flushing of irrigation system pipelines is an essential part of the maintenance program required for long-term success with microirrigation. Flushing will prevent accumulation of small particles and their buildup to a size that can plug emitters. Flushing frequency can vary according to both amount of flushing material and quality of the irrigation water, because of this laterals should flushed at least once a month (Smajstrla and Boman, 1999).

The emitters on the trickle irrigation systems could be easily clogged by poor management, resulting in loss of energy and water. This makes irrigation system, which has a high investment cost ineffective in a short time. Growers may return back to the other irrigation systems which have lower irrigation uniformity (Özekici, 1998).

The objectives of this research were to determine the effects of different fertilizers used in drip irrigation with different emitters on system performance and also to find solutions to increase the performance of drip irrigation systems.

MATERIALS AND METHODS

The research was conducted at a greenhouse located at the research station of Samandağ Vocational College, University of Mustafa Kemal, Hatay, in three consecutive seasons (spring 2001, fall 2001 and spring 2002). The research station is located in the coastal area of Samandağ, 600 m away from the Mediterranean Sea (36°08' N; 35°54' E) and a altitude of 3 m above sea level. During the study, average, maximum and minimum temperatures inside of the greenhouse are 22.9, 42.2 and 2.4°C, respectively.

Table 1: Average Values of Irrigation Water Quality in Seasons

	Growing season (S)		
Reasons for clogging	S_1	S_3	S_3
Physical			
Suspended materials (mg L^{-1})	6.92	4.15	5.31
Chemical			
pH	7.72	8.10	8.31
Dissolved material (mg L^{-1})	1.388	1.244	1.343
Mn (mg L^{-1})	<0.1	<0.1	<0.1
Total Fe (mg L^{-1})	0.10	0.12	0.09
Hydrogen Sulfide (mg L^{-1})	13.42	9.06	11.26
Biological			
Bacterial population (No. mL^{-1})	1,600,000	170,000	1,440,000

Table 2: Technical properties of lateral and emitters

	Laterals (L)		
Properties	L_1	L_2	L_3
Lateral diameter (mm)	16.60	16.00	16.00
Lateral thickness(*) (mm)	0.62	1.00	0.62
Operating pressure (m)	10.00	10.00	10.00
Discharge (L h^{-1})	2.75	4.00	1.70
Emitter spacing (cm)	20.00	25.00	20.00
Emitter length(*) (mm)	33.70	70.00	53.60
Emitter outlet diameter(*) (mm)	2.00	2.60	2.30

*Found by measurements

The water source was a 9 m deep well. The irrigation water was analyzed at the beginning of each growing season (Table 1). The irrigation waters, which effects drippers performance, were classified by Bucks *et al.* (1979) according to their clogging effects. The irrigation water used in this experiment fall into high risk class with regard to pH, hydrogen sulfide and bacterial population and average risk class with regard to dissolved materials and low risk class with regard to Mn, total Fe and suspended materials according to Bucks *et al.* (1979) classifications.

Drip irrigation system was set up with sand separator, screen filter with 200 mesh, fertilizer tank with 100 L capacity and a pump, water meter, valves and manometers. Submain pipeline which had ball valves and pressure regulators at the inlets were located for applying each fertilizer forms separately. In the system, three different laterals with different in-line emitters were used (Table 2).

The experimental design was set up in a split-strip plots with three replication. Main plots were included fertilizer treatments (F_0, F_1, F_2). Main plots were splinted by two different managements which included (M_1) and with no included (M_0) flushing and acid injections. In these plots, three different laterals (L_1, L_2 and L_3) were placed with three replications (Fig. 1). All factors in the experiment is given in detail below.

Table 3: Applied fertilizer quantity based on treatments (kg ha^{-1} season^{-1})

	Growing season (S)			
Fertilizer Form (F)	S_1 (spring 2001)	S_2 (winter 2001)	S_3 (spring 2002)	Total
$NH_4F_1NO_3$	554.62	603.48	406.29	1564.39
$Ca(NO_3)_2$	941.22	985.15	683.52	2609.89
KNO_3	285.66	357.32	216.38	859.36
K_2SO_4	643.43	804.83	487.37	1935.63
MKP	202.29	230.24	129.00	561.53
$NH_4F_2NO_3$	1109.24	1206.97	812.58	3128.79
K_2SO_4	906.24	1133.56	686.44	2726.24
MKP	202.29	230.24	129.00	561.53

F_0, control plots, included only irrigation water application.

F_1, total nitrogen was given as 25% sulfate and 75% nitrate forms with Ammonium Nitrate (NH_4NO_3), Calcium Nitrate ($Ca(NO_3)_2$), Potassium Nitrate (KNO_3), Potassium Sulfate (KSO_4) and Mono Potassium Phosphate (MKP).

F_2, total nitrogen was given as 50% sulfate and 50% nitrate forms with Ammonium Nitrate, Potassium Sulfate and Mono Potassium Phosphate.

M_0, no acid injection and flushing were performed.

M_1, acid injection and flushing were used to keep the pH value of fertilized water about 6-6.5, depending on the titration test results, a concentration of 1 mg L^{-1} phosphoric acid were applied. Moreover, at the end of the each season, laterals were flushed with 5 mg L^{-1} phosphoric acid solution.

L_1, a lateral with 2.75 L h^{-1} discharge rate and with emitters at every 20 cm.

L_2, a lateral with 4.0 L h^{-1} discharge rate and with emitters at every 25 cm.

L_3, a lateral with 1.7 L h^{-1} discharge rate and with emitters at every 20 cm.

Lengths of all laterals were 23 m and they were placed 50 cm away each other.

Fertigation was applied according to guidelines recommended by Bar-Yosef (1991) where, for greenhouse tomatoes, amount of NPK should be 450, 95 and 943 kg ha^{-1}200 day^{-1}, respectively.

Fertilizers were applied with every irrigation application. Fertigation was achieved by Burt *et al.* (1995) method which is called "quarter". Total applied amount of fertilizers in F_1 and F_2 treatments were given Table 3. Because of the control treatment, irrigation water was applied in F_0 treatment but no fertilizer was applied.

The amount of irrigation water applied was based on free surface evaporation from a Class A Pan. Manufacturing, placement and management of this pan was based on rules of Richard *et al.* (1998). Irrigation was started by tensiometer value, which was placed 30 cm deep from soil surface, not exceeding -25 cb.

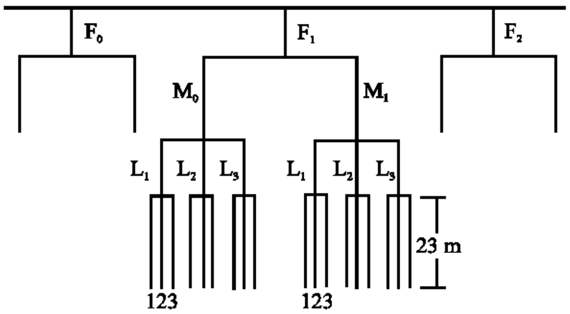

Fig. 1: Graphical layout of the experiment plan

The first growing season (S_1) was 145 days. In this season, total of 309.1 mm irrigation water given with twelve irrigations. The second growing season (S_2) was 165 days and a total of 216.4 mm irrigation water given with eleven irrigations. Third growing season (S_3) was 101 days and a total of 292.1 mm irrigation water given with ten irrigations.

Performance of emitters were tested at the beginning of the experiment according to ASAE Standards (1998). Laterals were raised 20 cm from the ground without elevation differences, irrigation water pressures in the lateral were adjusted according to manometers value at the beginning and end of the laterals by placing ball valves. Emitter flow variations were determined twice at the beginning (BS) and at the end of the (ES) each season for predetermined 50 emitters for each laterals. To determine the flushing effects, emitters discharge rates were tested at the end of the season before (ESBF) and after (ES) the flushing. During the tests, water temperatures were measured but since the emitters has turbulent flows, the effects of water temperature on discharge rates were neglected according to literature (Peng *et al.*, 1986).

Emitter flow variation, q_{var}, (WU *et al.*, 1986), coefficients of manufacturing variation, CV_m, (Solomon, 1977), statistical uniformity, U_s, (Bralts *et al.*, 1981), emission uniformity, EU and design emission uniformity, EU_d, (Keller and Karmeli, 1974) equations were used for evaluation of the system performance according to ASAE standards (1998).

RESULTS AND DISCUSSION

Emitters flow tests: At the beginning of the experiment, a series of the tests related to the emitters were performed and q_{mean}, CV_m, q_{var}, U_s EU and EU_d performance values were determined (Table 4).

Results showed that, the CV_m values of L_1 and L_2 were in the category of Excellent. CV_m values of L_3 were in

Table 4: Some performance indicators of the laterals at the beginning of the experiment

Criteria's	L_1	L_2	L_3
q_{mean} (mL h^{-1})	2688.00	3995.00	1800.00
CV_m	0.02	0.02	0.12
q_{var} (%)	5.60	4.40	44.00
U_s (%)	98.50	98.90	83.40
EU (%)	98.00	98.70	88.20
EU_d (%)	94.00	93.00	73.00

Table 5: Classification of the CV_m, U_s and EU indicators of laterals at the beginning of the experiment according to ASAE (1998) standards

CV_m	Classification	U_s (%)	Classification	EU (%)	Classification
<0.05	Excellent	95-100	Excellent	94 ≤	Excellent
0.05-0.07	Average	85-90	Good	81-87	Good
0.07-0.11	Marginal	75-80	Fair	68-75	Fair
0.11-0.15	Poor	65-70	Poor	56-62	Poor
>0.15	Unacceptable	≤ 60	Unacceptable	≤ 50	Unacceptable

Table 6: Duncan's Multiple Range Test Results of Flow Rate Decreases in Season×Fertilizer×Flushing×Lateral Interaction

Fertilizer (F)	Flushing (M)	Lateral (L)	Seasons (S) S_1	 S_2	 S_3
F_0	M_0	L_1	7.353f-p*	5.797j-t	4.590n-t
		L_2	6.313h-s	5.453k-t	2.697st
		L_3	4.023p-t	12.48bcd	5.640j-t
	M_1	L_1	6.383h-s	3.917p-t	3.077rst
		L_2	5.833ıt	4.410o-t	3.580q-t
		L_3	10.96c-f	9.133d-k	12.54bcd
F_1	M_0	L_1	9.363c-j	6.800g-r	6.170h-s
		L_2	6.907g-q	8.080e-o	3.343q-t
		L_3	12.78bcd	17.40a	15.85ab
	M_1	L_1	10.14c-g	2.133t	5.493k-t
		L_2	6.893g-q	6.763g-r	6.387h-s
		L_3	12.96bc	17.83a	11.43cde
F_2	M_0	L_1	8.680e-m	6.073h-s	4.023p-t
		L_2	8.500e-m	5.710j-t	3.383q-t
		L_3	11.11cde	9.627c-h	8.700e-l
	M_1	L_1	8.213e-n	5.357l-t	3.967p-t
		L_2	5.857l-t	5.653j-t	4.963m-t
		L_3	9.777c-h	9.547c-I	10.86c-f

*Treatments marked with the same letter are in the same group at the p≤0.05 level

the category of Poor. According to the other criteria's (U_s and EU) L_1 and L_2 were in the excellent category and the L_3 was in the good category (Table 5).

Emitter discharge rates at the end of the each season were lower than the values at the beginning of the each season, particularly, at the end of the laterals. In agreement with this, some studies have pointed out similar findings (Adin and Sacks, 1991; Ravina *et al*., 1992; Puig-Bargues *et al*., 2005). Although flushing application had reclaimed some of the clogged emitters and increased the emitter discharge rates, this was not found to be statistically significant. It was observed that, at the end of the flushing applications, clogging of some emitters at the end of the laterals were increased as a result of dragged materials.

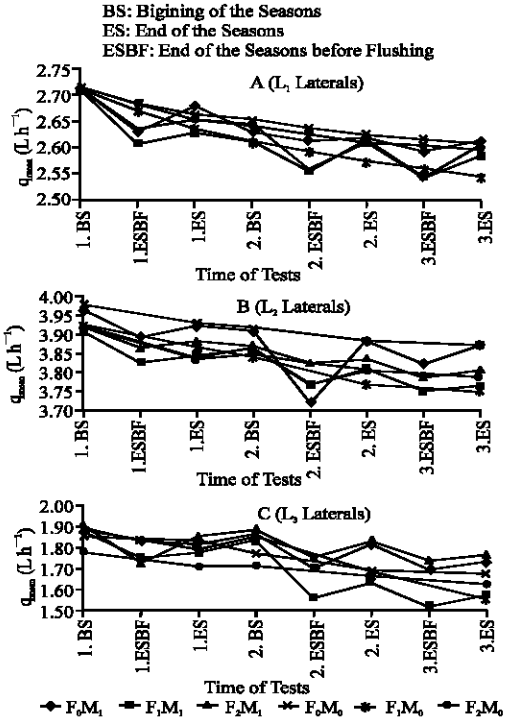

Fig. 2: Emitter discharge rate variations in the experiment

L_1 and L_2, in general, had showed consistent discharge rate variations in themselves. The highest emitter discharge rate decrease was in F_1 and the lowest emitter discharge rate decrease was in F_0 resulted emitter clogging (Fig. 2A and B). However, there were high and inconsistent variations of emitter discharge rates in comparison with other laterals in L_3. CV_m values of L_3 which had the lowest discharge rate were the highest because of this, their values of q_{mean} were inconsistent in all treatments compared to the others (L_1 and L_2). In this group, it was determined that the highest emitters discharge rate decrease was in F_1 and the lowest emitters discharge rate decrease was in F_2 (Fig. 2C). In control treatment (F_0M_0) 74% of L_1 emitters, 95% L_2 emitters and 49% L_3 emitters showed 0-5% discharge rate decrease however emitters of L_3 showed up to 50% discharge rates decrease.

The maximum (25-100%) discharge decrease were determined; 4% of L_1 in F_1M_0 groups, 0.67% of L_2 in F_2M_0 and 0.67% of L_2 in F_2M_1 groups, 14.02% of L_3 in F_1M_0 and 13.34% of L_3 in F_1M_1 groups.

When the emitters which had clogging and decreased flow rate at some percentages were evaluated the highest clogging and thereby lower flow rates were observed in F_1 applications. The flushing management, although not statistically significant, was efficient in preventing clogging and increased flow rates. These results are in good agreement with the findings of Hills *et al*. (1989).

Table 7: Average performance values of the laterals at the end of the seasons (%)

			q_{var} (%)			U_s (%)			EU (%)			EU_d (%)		
F	M	L	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
F_0	M_0	L_1	6.8	6.7	8.5	98.2	98.2	97.9	97.7	97.8	97.3	94.5	94.7	91.6
		L_2	6.1	6.5	6.7	98.5	98.5	98.5	98.3	98.1	98.0	95.1	95.0	94.2
		L_3	51.1	66.4	53.3	79.4	86.0	88.5	88.8	91.6	92.6	65.1	36.2	69.4
	M_1	L_1	6.7	7.2	8.7	98.3	98.2	98.2	97.9	97.8	97.8	94.1	93.8	91.7
		L_2	5.3	4.6	9.9	98.7	98.8	98.1	98.4	98.5	98.0	95.5	96.1	90.3
		L_3	52.9	59.5	56.2	77.7	78.4	78.6	89.0	88.0	89.8	60.8	56.5	64.1
F_1	M_0	L_1	7.1	12.6	32.5	98.3	97.6	93.1	97.9	97.1	91.8	94.3	89.7	66.5
		L_2	8.2	9.0	9.2	97.6	97.7	97.9	97.3	97.3	97.3	93.5	92.5	91.7
		L_3	53.3	99.9	99.9	80.6	60.7	64.8	90.5	70.1	69.0	67.2	0.1	0.2
	M_1	L_1	11.9	10.3	22.3	97.5	97.6	95.5	97.1	97.1	94.9	89.3	91.9	78.3
		L_2	40.2	10.3	12.7	93.6	97.8	97.5	95.6	97.5	97.0	62.0	92.7	89.9
		L_3	59.3	96.8	89.1	79.0	60.2	64.8	86.6	59.2	66.2	48.4	4.4	15.6
F_2	M_0	L_1	10.1	8.2	16.7	97.9	98.1	96.9	97.4	97.5	96.3	90.8	92.9	83.9
		L_2	32.3	9.0	18.8	94.7	97.9	96.7	95.9	97.6	96.3	68.1	92.8	82.0
		L_3	26.9	35.8	48.4	90.2	88.7	86.0	95.4	94.3	92.3	83.0	77.0	68.4
	M_1	L_1	8.6	11.9	19.8	98.0	97.4	96.4	97.5	96.8	96.3	92.3	90.2	80.8
		L_2	8.3	11.1	10.1	97.8	97.5	97.6	97.4	97.1	97.2	93.5	90.8	91.5
		L_3	56.7	58.0	73.8	76.0	73.1	71.2	88.3	85.8	85.3	60.7	55.3	32.3

Moreover, the L_3 emitters which had relatively smaller holes tend to have more clogging and lower flow rates. As emitters have bigger holes, the clogging was less and the flow rates were higher. Similar relationships were also reported by Keller and Bliesner (1990) and Chigerwe *et al.* (2004).

Emitter discharge rate variations based on both seasons and treatments were tested statistically by using MSTAT-C computer software. Fertilizer, lateral, season×lateral, fertilizer×lateral, season×fertilizer×flushing×lateral interactions were significant at 1% and season×flushing, season×fertilizer × flushing, season×fertilizer×lateral, flushing×lateral and fertilizer×flushing×lateral interactions were significant at 5% level by variation test. Treatment means were evaluated and compared with Duncan multiple range test (Table 6). The highest flow rate decreases were observed in $S_2F_1M_0L_3$ and $S_2F_1M_1L_3$ and the lowest flow rate decrease was in $S_2F_1M_1L_1$. This results indicated that emitter flow rates were more important factor than the others for emitter discharge rate decreasing caused by clogging.

Evaluation of emitter performances: The system performance indicators (q_{var}, U_s, EU and EU_d) were calculated at the end of the each season by using emitter flow test results (Table 7). The lowest emitter flow variation (q_{var}) was found in $F_0M_1L_2$ interaction in second (S_2) season and the highest emitter flow variation was found in $F_1M_0L_3$ interaction in second (S_2) and third (S_3) seasons.

Percentage statistical uniformity variation among the seasons were calculated and these values were analyzed statistically. Lateral and season×lateral interactions was significant at 0.1% level and fertilizer, fertilizer×lateral and season×fertilizer×lateral interactions were significant at 5% level by variation test. To determine the effect of treatments on U_s variations, values of mean were tested with Duncan test. Season×fertilizer×lateral interactions had twelve statistical groups with in 95% confidence level. The highest variation was in $S_2F_1L_3$ interaction and the lowest variations were in $S_2F_2L_2$, $S_3F_0L_2$, $S_1F_0L_1$, $S_3F_0L_1$, $S_1F_0L_2$, $S_2F_2L_1$, $S_2F_0L_1$, $S_2F_1L_2$ and $S_2F_0L_2$ interactions.

The effect of treatment on EU variation were analyzed with Duncan test. Fertilizer, lateral, season×lateral, fertilizer×lateral and season×fertilizer×lateral interactions were significant at 0.1% level and, season×fertilizer interactions was significant at 5% level. There were nine different Duncan groups in season×fertilizer×lateral interactions 95% confidence level. The biggest EU variation was in $S_2F_1L_3$ interaction with the lowest flow rates and the lowest variation was in $S_2F_1L_2$ interaction with the highest flow rates. Similarly, Chigerwe, *et al.* (2004) reported that a well designed micro-tube systems with high flow rates generate high uniformity, even at extremely low head (0.1 m) and present lower clogging problems and higher placement flexibility than the low flowing systems.

Since the minimum emitter flow rates in the system were used in calculation of design emission uniformity (EU_d), fully or partially clogged any emitter in the system could lower the EU_d values of the system. Therefore this is a not good method for evaluating system performance in the field. As indicated in literature, this evaluation method should only be used when more than one emitters used per plant or when multiple outlets emitters were used. Since one emitter per plant was used in this experiment and there were also fully clogged emitters, the variation tests were not performed.

As a result of this study, It can be concluded that in drip irrigation systems fertigation effects the emitter flow differences. The type of applied fertilizers effected the performance. The lowest performance was observed in F_1 (Calcium and sulfate forms were used together) treatments. The pH adjustments and flushing particularly gains importance when these forms of fertilizers were used. There were no significant differences between flushing applications statistically but these applications increased emitter discharge rates. Further research should be conducted to determine the effect of flushing frequency on emitter clogging.

By the end of the experiment, L_2 laterals which had the highest discharge rates, had the highest performance and L_3 laterals which had the lowest discharge rates, had the lowest performance. Thus, choosing emitters with the higher discharge rates must be important for resistant to emitter clogging.

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