

TRICKLE IRRIGATION: EMITTER CLOGGING AND OTHER FLOW PROBLEMS

R.G. GILBERT, F.S. NAKAYAMA, D.A. BUCKS, O.F. FRENCH and K.C. ADAMSON
U.S. Water Conservation Laboratory, 4331 East Broadway, Phoenix, AZ 85040 (U.S.A.)
Contribution from the Science and Education Administration, Agricultural Research, U.S.
Department of Agriculture.

(Accepted 13 October 1980)

ABSTRACT

Gilbert, R.G., Nakayama, F.S., Bucks, D.A., French, O.F. and Adamson, K.C., 1981.
Trickle irrigation: emitter clogging and other flow problems. *Agric. Water Manage.*, 3:
159-178.

Trickle irrigation experiments with Colorado River water on citrus trees in southwestern Arizona were conducted to develop water treatment methods for preventing emitter clogging and maintaining long-term operation of the system under actual field conditions. Eight trickle emitter systems in combination with six water treatments were evaluated during a comprehensive 4-year study. Emitter clogging was related to emitter design and to degree of filtration treatments of Colorado River water. If not positioned upright, emitters designed with moving parts were more susceptible to malfunctioning and clogging. Emitters with flexible membranes either failed after a few months of use with chemically conditioned water or showed serious deterioration and decomposition after 4 years. Five of the eight emitter systems required sand and screen (200 mesh) filtration plus chemically conditioned water to keep suspended materials from physically clogging the emitter. However, two emitter systems with the same design but different flow rates have continued to operate with only screen (50 mesh) filtration. For emitters unaffected by material deterioration, the water conditioned continuously with acid alone was just as effective as a combination of continuous or intermittent chlorine and acid treatments in reducing emitter clogging. The dominant causes of emitter clogging and flow reduction were physical particles; next, and minor in comparison, was the combined development of biological and chemical deposits.

INTRODUCTION

Trickle irrigation systems are presently being used successfully on a variety of row and tree crops. However, emitter clogging, which adversely affects the rate of water application and uniformity of distribution (Nakayama and Bucks, 1980) and increases operating costs, continues to be the greatest problem of such systems. Researchers and manufacturers have approached solutions to the clogging problem by developing emitters that require less or minimum maintenance (Wilson, 1972; Solomon, 1977) and by improving or

altering the quality of source water before it reaches the emitters (Ford and Tucker, 1975; Ford, 1975a, 1975b, 1976, 1979; Bucks et al., 1977; Nakayama et al., 1977, 1978). In general, water sources with low amounts of the following constituents are recommended: (1) suspended inorganic and organic materials; (2) dissolved chemical constituents that cause scaling such as calcium carbonate, iron, and manganese oxide; and (3) microbes that cause slime development and agglomeration of suspended materials, or that are involved in biochemical accumulation of heavy metals or sulfides. The importance of water quality in trickle irrigation systems has been emphasized (Ford, 1977). Recommendations and guidelines for preventive maintenance, which include water filtration, chemical treatment, pipeline flushing, and field inspection, have also been formulated (Bucks et al., 1979).

This report summarizes results of final examination of clogged and partially clogged emitters after 4 years of field operation. The causes of emitter clogging and other emitter flow problems associated with eight types of trickle emitter systems and six different treatments of Colorado River water were determined.

EXPERIMENTAL DESIGN AND PROCEDURES

Background. A field study was established in January 1975 on 0.8 ha with 200 mature Valencia orange trees at Tacna, Arizona, 64 km east of Yuma, Arizona, in the Wellton-Mohawk Irrigation and Drainage District. Details of the experimental site, equipment, chemical and biological water analysis, and cultural procedures were described previously (Nakayama et al., 1978; Gilbert et al., 1979).

Types of emitters. Eight different types of emitters were selected from a representative sampling of emitter designs commercially available (Table I). The emitters were fitted into 1.3-cm polyethylene tubing and circled symmetrically around each of the four trees per subplot.

Water treatments. Water treatments (Table II) were selected on the basis of results obtained by researchers who successfully prevented emitter clogging with other water sources under different environmental conditions (Wilson, 1972; McElhoe and Hilton, 1974; Pelleg et al., 1974; Ford and Tucker, 1974; Ford, 1975a). The water treatments were varied by degree of filtration for removal of suspended load and amount of chemical conditioning for controlling pH and preventing biological slime development. The water in Treatments A and C received no chemical conditioning. In Treatment E, dilute calcium hypochlorite and sulfuric acid solutions were injected separately into the inlet side of the sand filter. Injection rates of the chemicals were adjusted to attain a pH of 7, and the available chlorine in the water at the outlet of the screen filter was about 1.0 mg/l. In Treatments B and D, acid and hypochlorite were injected intermittently only during the last hour of irrigation,

TABLE I

Description of trickle emitters

Emitter no.	Type	Flow rates ^a (l/h)	Orifice size ^b (mm)
1	Long-path, capillary tubing	6.5	0.95
2	Long-path, spiral-grooved, manual flush	7.6	0.95
3	Long-path, spiral-grooved, manual flush	3.8	0.74
4	Diaphragm, expandable orifice	3.4	0.58
5	Short-path, spiral-grooved, removable insert	5.7	0.64
6	Automatic, needle-flush valve	3.8	0.58
7	Automatic, ball-flush valve	4.6	0.27
8	Single vortex	4.2	0.64

^aInitial flow rate of emitter at 15 psi (104 kPa).

^bOrifice size represents the minimum average internal diameter of the water flow path.

TABLE II

Description of water treatments

Treatment	Type of treatment	
	Filtration ^a	Chemical
A	Screen (50-mesh)	None
B	Screen (50-mesh)	Chlorine and acid — intermittent ^b
C	Sand + screen (200-mesh)	None
D	Sand + screen (200-mesh)	Chlorine and acid — intermittent ^b
E	Sand + screen (200-mesh)	Chlorine and acid — continuous ^c
F	Sand + screen (200-mesh)	Acid — continuous ^c

^aThe sand filter medium was No. 20 silica sand; the screens were stainless steel, cylinder-type commercial units.

^bIntermittent chemical treatment: Chemicals were injected only during the last hour of irrigation cycle. The residual chlorine concentration was 10 mg/l and the acid adjusted the river water to pH 7. Chemical injection was started after 278 days of operation for Treatment B.

^cContinuous chemical treatment: Chemicals were injected during the complete irrigation cycle. The residual chlorine concentration was 1.0 mg/l (Treatment E) and the acid adjusted the river water to pH 7 (Treatments E and F).

so that the treated water filled all lines from the treatment shed to the lateral ends in the field. This produced residual chlorine concentrations of about 10 mg/l and adjusted the pH to 7. In Treatment F, dilute sulfuric acid was injected continuously at a rate sufficient to adjust the water to pH 7.

All chemicals were injected into the system before the water was filtered

to reduce bacterial growth within the screen and sand filters, and only plastic fittings were used after the injection point. Diluted acid was injected into the system upstream from the hypochlorite injection point to allow for acid dilution before these two chemicals were mixed.

The original laboratory-fabricated stainless steel screens developed seam breakages, especially on Treatments A and B. Therefore, these treatments, which were initially 40-mesh and 200-mesh screen filters, respectively, were both converted to 50-mesh, commercial-type stainless steel screen units after 259 days operation. Later, after 278 days operation, Treatment B was changed to an intermittent chlorine and acid treatment to be comparable to Treatment D, except for the filtration method. At the same time, new 200-mesh screen units were installed after the sand filter on Treatments C, D, E, and F to prevent sand from reaching the emitters in case of filter failure or errors in valve adjustment during backwashing operations. Commercial, epoxy-bonded, glass-fiber swimming pool filters with 0.18-m² filter area and Number 20 silica sand were used to minimize reaction of the equipment with treatment chemicals. When suspended loads were high, the sand filters were backwashed daily before the system was turned on. Otherwise the system was backwashed at least once weekly or whenever the filter outlet pressure decreased 69 kPa below the working inlet pressure of about 276 kPa. All screens were dismantled and cleaned when sand filters were backwashed.

Assessing emitter clogging. During 4 years of operation the degree of emitter clogging was directly related to the reduction in average flow rates for each experimental subplot of four trees. Two turbine water meters in series monitored water volumes and discharge rates were calculated that represented the average flow rate per emitter. Occasionally, flow rates of an individual emitter system were determined by measuring and timing the discharge volume with a graduated cylinder and stop watch. However, when the experiment was terminated, flow rates of every emitter from all eight emitter systems were recorded. Emitters with flows reduced to less than 50% of design flow were considered clogged. Each was tagged, later removed, carefully dissected, and microscopically examined to determine the causes of clogging and flow reduction. No emitters were removed or unclogged during the experiment, unless the system had completely failed.

RESULTS AND DISCUSSION

Effect of water treatments

The effectiveness of each water treatment in preventing emitter clogging can be seen in the number of emitters that were operating at less than 50% of design flow at the end of the experiment for the eight emitter systems (Table III). We found that screen filtration alone (Treatments A and B) was inadequate, since overall emitter failure was 68%. In contrast, a combination of

TABLE III

Effect of water treatment on clogging of trickle emitters^a

Water treatment	Number of emitters clogged ^b	Percent clogged
A	205	68
B	205	68
C	68	23
D	53	18
E	41	14
F	25	8
Totals	597	33

^aPooled observations for 300 emitters of eight different designs.^bClogged emitters had flow rates of less than 50% of design flow.

sand and screen filtration (Treatment C) reduced the clogging rate to 23%. Chemically conditioning the water (Treatments D, E, and F) reduced it even further. Emitter performance was best with continuous acid (Treatment F), where we observed a clogging rate of only 8%. These results indicated that the most efficient treatment for prevention of emitter clogging was continuous acid for pH control of carbonate formation and precipitation coupled with sand and screen filtration.

Individual emitter performance

The clogging rate for each of the eight emitter systems varied with the water treatment (Table IV, V, and VI). Therefore, the performance of each individual emitter system will be discussed separately.

Emitter No. 1 (Fig. 1A) performed efficiently with sand and screen filtration; its clogging rate was 27% (Table IV). Chemical conditioning continuously with acid (Treatment F) maintained flow rates of 71% of design flow (Table V). With only screen filtration (Treatments A and B), the emitter failed after 278 days because of physical clogging. Microscopic examination (Fig. 1) of plugged emitters indicated that physical blockage had occurred mainly at the inlet end of the capillary tubing. This emitter was normally installed in the system by sliding the capillary tube into a hole in the larger polyethylene supply line. Thus, the inlet end could be in the midst of accumulated sediment in the bottom of the supply line. All the other emitters had inlet stems a few millimeters long that were inserted at right angles to the supply line. If the emitter was installed perpendicular to the ground, then water from the upper portion of the supply line would flow into it.

Emitter No. 2 (Fig. 2A) performed efficiently regardless of the water treatment or method of water filtration. Even with screen filtration alone, the

TABLE IV

Effect of water filtration method on clogging of eight trickle emitter systems^a

Emitter system	Screen (50 mesh) filtration		Sand and screen (200 mesh) filtration	
	No. emitters	Percent clogged	No. emitters	Percent clogged
1	56	100	112	27
2	40	5	80	18
3	80	20	160	38
4 ^b	88	0(84)	176	0(70)
5	72	100	144	22
6	96	100	192	13
7	80	100	120	4
8	88	100	176	21
Totals	600	68(81)	1200	16(26)

^aEmitters with flow rates of less than 50% of design flow were considered clogged. Results for screen filtration are the combined data from Treatments A and B. Results for sand and screen filtration are the combined data from Treatments C, D, E, and F.

^bEmitter No. 4 failed because flows increased to greater than 150% of design flow. The percentage that failed because of fast flows is indicated in parentheses. Additional information on these flow problems with Emitter No. 4 is presented in Table VI.

TABLE V

Percent of design flow after 4 years of operation for six water treatments and eight emitter systems

Emitter systems	Water treatments ^a					
	A	B	C	D	E	F
	(Percentage of design flow)					
1	PC ^b	PC	51	66	62	71
2	76	78	51	70	72	83
3	59	67	55	52	76	62
4	162	CD ^c	169	CD	CD	111
5	PC	PC	59	73	73	51
6	PC	PC	110	134	121	86
7	PC	PC	73	118	98	93
8	PC	PC	65	69	85	96

^aEmitter systems and water treatments are listed in Tables I and II.

^bPC — emitters failed after 278 days because of physical clogging due to inadequate filtration of high suspended loads.

^cCD — emitters failed after 557 days because of chemical deterioration of the expandable orifice on the rubber diaphragm, which increased flow rates to at least twice the design flow.

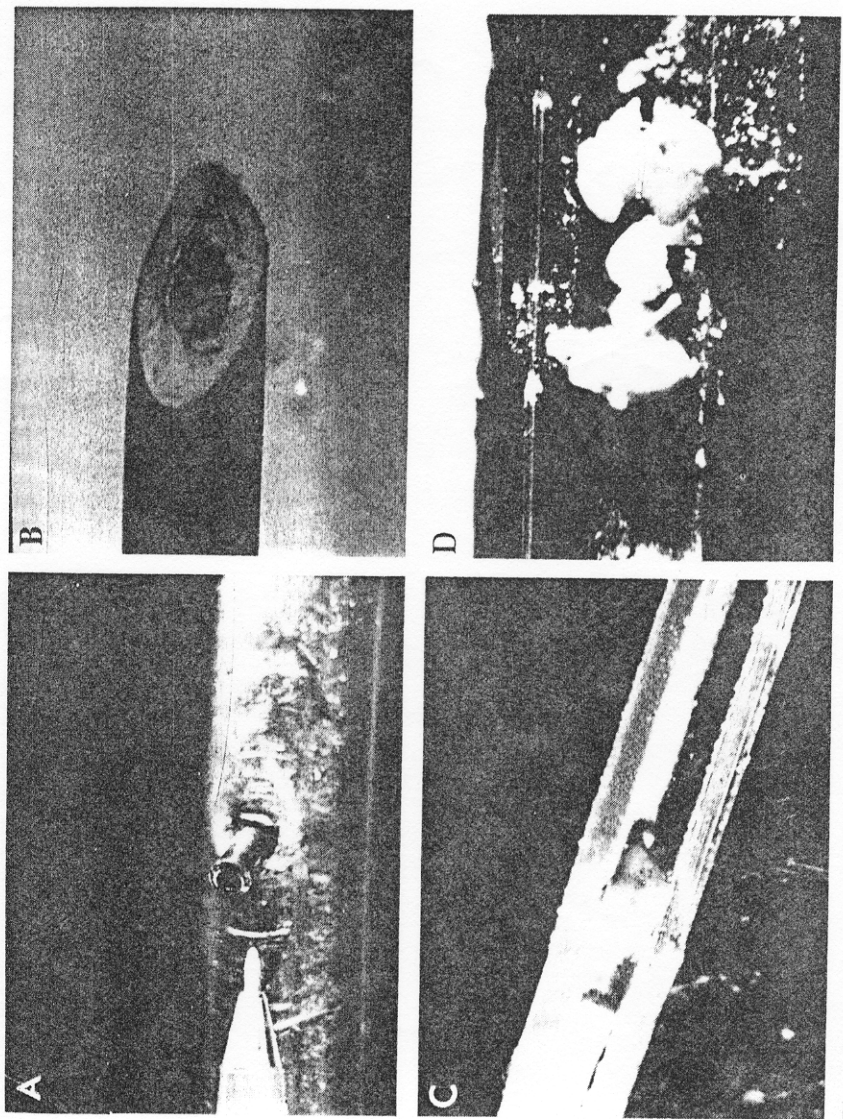


Fig. 1. Emitter 1 with representative clogging problems. A: Exit port of a long-path, capillary tube emitter on a lateral line. B: Plastic particle (white PVC) plugged the entrance of the capillary tube. C: Sand grain and accumulated sediment plugged the capillary tube. D: Plastic saw filling (white PVC) and part of an insect body plugged the capillary tube.

TABLE VI

Influence of water treatment on flow problems of Emitter No. 4

Water treatment	Condition of emitters ^a		
	No. clogged	No. fast flow	Percent failed
A	0	30	68
B	0	44	100
C	0	32	73
D	0	44	100
E	0	44	100
F	0	4	9
Totals	0	198	75

^a Each water treatment was delivered to 44 emitters. Individual emitters with flow rates exceeding 150% of design flow were considered as failed.

clogging rate was only 5% (Table IV). Sand and screen filtration increased the emitter clogging rate to 18% by unknown clogging factors, but chemical conditioning (Treatments D, E, and F) prevented the clogging and flow-reducing conditions that occurred with untreated water (Treatment C) (Table V). Microscopic examination of the few emitters that clogged indicated that physical and biological factors were responsible, either separately (Fig. 2B, 2C) or in combination (Fig. 2D).

Usually the emitter flow seemed to be reduced first by some physical factor that allowed microbial slimes to develop, especially toward the end of the spiral-groove (Fig. 2C). *Pseudomonas stutzeri* and *Flavobacterium lutescens* were the major bacteria detected in the biologically clogged emitters (unpublished data). The process occurred even in chlorinated systems. As the microbial slime continued to develop in the emitter, its flow rate was further reduced and even more chlorine was necessary for biological control than was present in the treated supply water. Eventually the emitter would have become completely plugged by microbial slime. The microbially plugged emitter was then a potential source of the microbes, which could colonize another emitter when the flow was periodically reduced. Biological slime development of this type was a slow process, but after a few years operation, it could become a very serious problem. Therefore, for long-term operation, periodic chlorination would be recommended.

Emitter No. 3 (Fig. 2A) was identical to Emitter No. 2 but had half the design flow rate. It performed efficiently regardless of water treatment (Tables IV and V). The relative results were similar to those from Emitter No. 2, except that the clogging rates were slightly higher (Table IV) and the flow rates were generally lower (Table V). This probably resulted from the smaller diameter spiral-grooved flow path, which was slightly more susceptible to clogging problems (Table I). Also, the unexplained increase in clog-

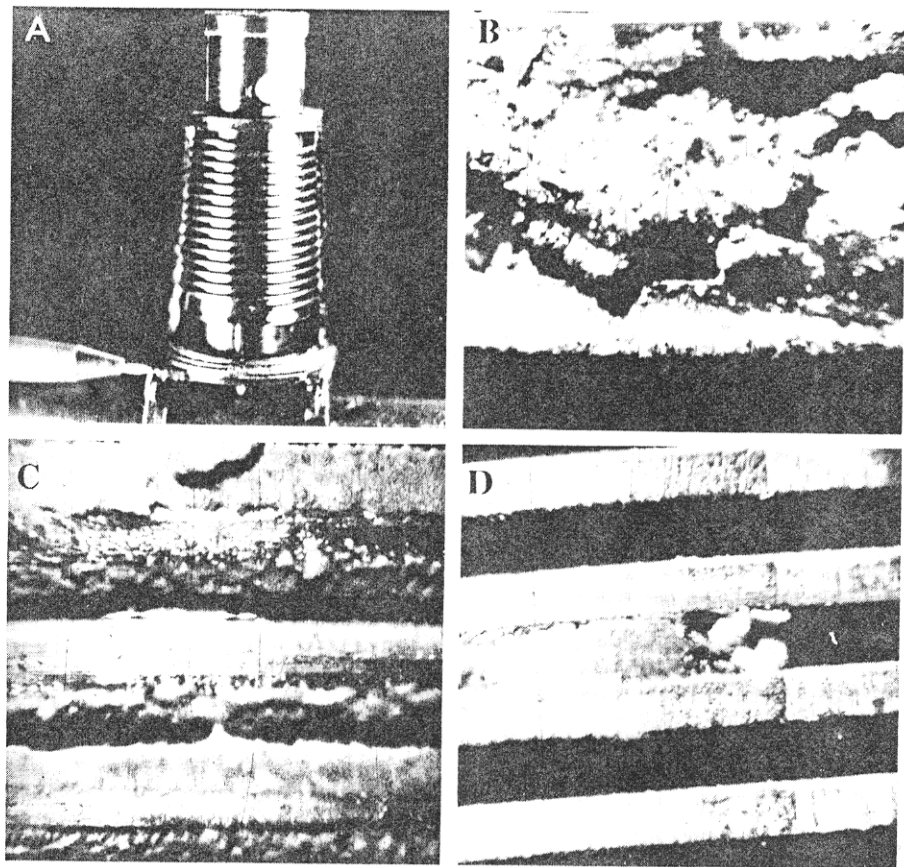


Fig. 2. Emitters 2 and 3 with representative clogging problems. A: Long-path, spiral-grooved, manual flush type emitters on a lateral line. B: Sediment and carbonates clogged the entrance to the spiral groove. C: Microbial slime development in the spiral groove clogged the emitter. Two major bacteria were detected in biologically clogged emitters: *Pseudomonas stutzeri* and *Flavobacterium lutescens*. D: Plastic particle (white PVC) lodged at molding seam of spiral groove and reduced flow, and then microbial slime development clogged the emitter.

ging rates and flow reduction with sand and screen filtration (Treatments C and D) occurred again with this emitter; again, chemical conditioning (Treatments E and F) prevented these problems. Microscopic examination of clogged emitters showed that a combination of physical and biological factors similar to those described for Emitter No. 2 (Fig. 2) was responsible.

Emitter No. 4 (Fig. 3A) never developed any plugging problems. However, after 18 months with acid and chlorine conditioning (Treatments B, D, and

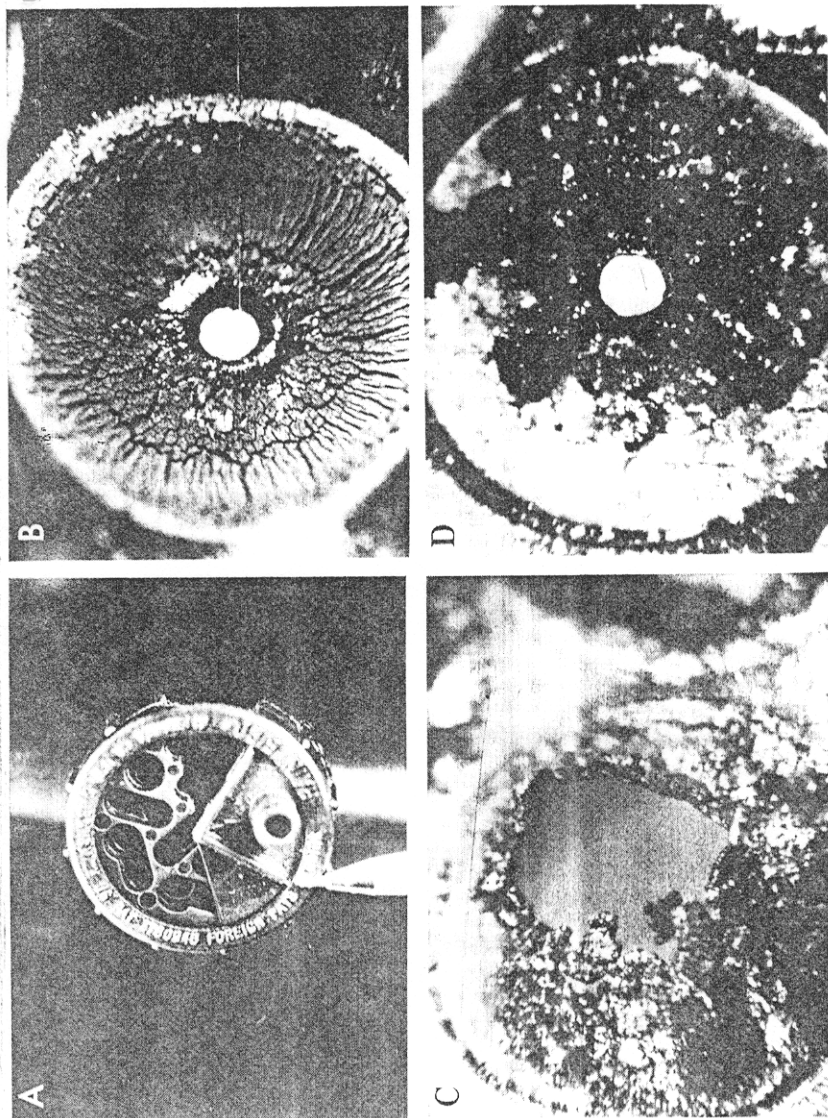


Fig. 3. Emitter 4 with representative flow problems. A: Multichambered, expandable rubber orifice diaphragm emitter on a lateral line. B: The rubber orifice diaphragm was deformed and deteriorated by chlorine and acid (Treatments B, D, and E) after 18 months. The condition increased flow rates to more than 150% of design flow. C: The rubber orifice diaphragm was extremely deteriorated after 4 years treatment with only screen (50 mesh) filtration (Treatment A). D: The rubber orifice diaphragm was colonized and severely decomposed by microbial action after 4 years treatment with sand and screen (200 mesh) filtration and continuous acid (Treatment F). Also, emitters treated with unconditioned water, Treatment C, were even more severely decomposed.

E), the emitter flow rates were 150% of design flow (Tables V and VI). Apparently, the acid and chlorine reacted with the rubber diaphragm, deforming and deteriorating it (Fig. 3B). Furthermore, after over 4 years operation with unconditioned water (Treatments A and C) flow rates exceeded 150% of design flow. Also, with continuous acid (Treatment F) flow rates were starting to increase (Table V), but only 9% of the emitters had failed after 4 years of operation (Table VI). Microscopic examination of emitters from Treatments A, C, and F revealed considerable microbial colonization, decomposition, and physical deterioration of the expandable rubber orifice diaphragm (Figs. 3C, 3D). Although this emitter performed more efficiently during the first year of operation than all other emitter systems used, our results indicated that the rubber diaphragm material should not be expected to last much longer than 4 years, regardless of the water treatment.

Emitter No. 5 (Fig. 4A) required sand and screen filtration for efficient operation (Table IV). Chlorine and acid (Treatments D and E) kept flow rate higher, but continuous acid (Treatment F) (Table V) did not help. The emitter was similar in design to emitters 2 and 3, but its smaller flow path made it much more susceptible to physical clogging problems (Table I). With only screen filtration (Treatments A and B) it failed after 278 days of operation. Microscopic examination of clogged emitters from Treatments C, D, E, and F indicated that clogging and flow reduction were caused mostly by physical factors, such as sand grains and plastic particles.

Emitter No. 6 (Fig. 5A) with only screen filtration (Treatments A and B) failed after 278 days because of physical clogging. Sand and screen filtration were required to prevent these problems (Table IV). The emitter, which had internal moving parts, probably would have performed better if it had been inserted into the supply line in an upright position.

We had randomly inserted these emitters into the supply line without attempting to position them upright so that the automatic needle-flush valve would operate as designed in all emitters. Those emitters positioned on the horizontal or below never benefitted from the automatic water pressure-gravity flushing mechanism. In time they became essentially static type emitters and the position of the needle-flush valve controlled the flow rates. If the valve was open, the flow rates were higher than designed. If it was closed, the flow rates were as designed. Without the benefit of the flushing action, the emitter was more susceptible to clogging by accumulated sediment (Fig. 5B) and other particles, such as sand grains (Fig. 5C) and plastic fragments. Furthermore, even with emitters installed upright, flow problems would occur if suspended materials caused the needle-flush valve to stick either closed or open. Therefore, flow rates greater than design flow in Treatments C, D, and E (Table V) were caused by factors that prevented the needle-flush valve from closing properly. The even greater increases in flow rates in Treatments D and E resulted from reaction of the silicone rubber

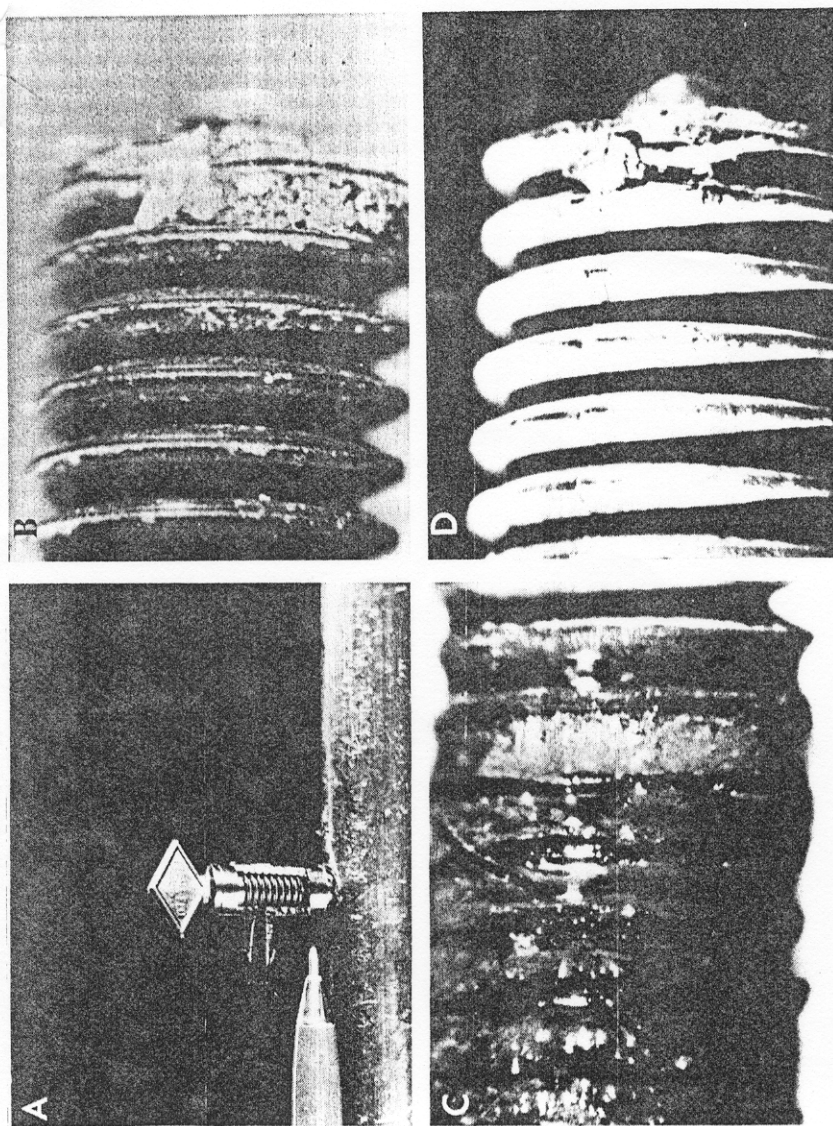


Fig. 4. Emitter 5 with representative clogging problems. A: Short-path, spiral-grooved, removable insert emitter on a lateral line. B: Plastic particle (white PVC) and microbial slime clogged the entrance of the spiral groove. C: Microbial slime developed extensively in the spiral groove causing emitter clogging and material deterioration of the plastic insert. D: Organic detritus clogged the entrance of the spiral groove.

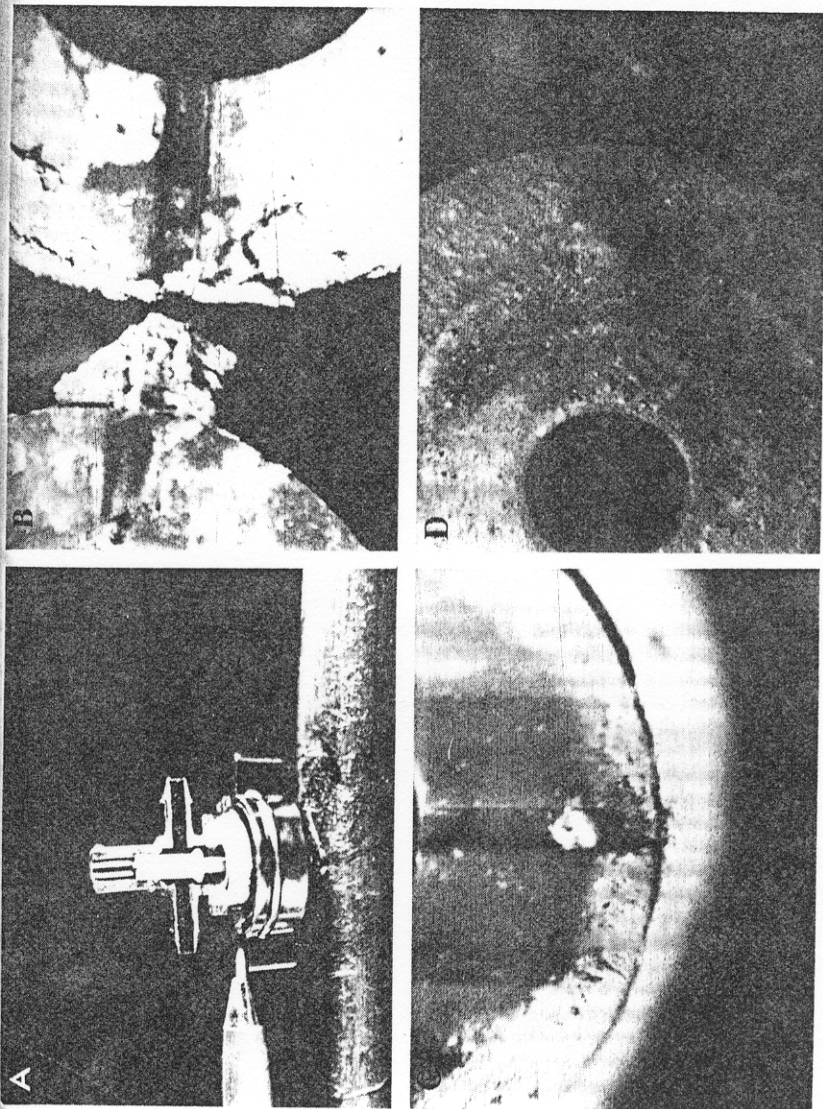


Fig. 5. Emitter 6 with representative clogging problems. A: Automatic silicon rubber disc/needle-flush valve emitter on a lateral line. B: Sediment closed the needle-flush valve and clogged the emitter. C: Sand grain lodged in flow path of needle-flush valve clogged the emitter. D: A distinct "bulge" on the surface of the silicon rubber disc was caused by chlorine and acid (Treatments D and E). When the bulge was positioned over the flow path of the needle-flush valve, it clogged the emitter; when positioned elsewhere, it prevented closing of the flush valve, which increased flow rates.

disc with the chlorine and acid. The disc swelled and became deformed irregularly, so that the needle-flush valve remained open. Continuous acid (Treatment F) did not produce these effects and maintained the most efficient flow rates for this emitter. Flow rates probably would have been even better with this treatment if the emitter had been installed properly.

Microscopic examination of clogged emitters showed that accumulated sediment and individual sand grain and plastic fragments caused most of the clogging (Figs. 5B, 5C). Emitters receiving chemically conditioned water (Treatments D and E) developed a unique clogging problem. The chlorine and acid had caused the silicone rubber disc to develop a pronounced "surface bulge" (Fig. 5D), that blocked the grooved flow channel of the needle-flush valve and plugged the emitter. The surface bulge could also have contributed to the increased flow rates (Treatments D and E) (Table V) by keeping the flush valve open when the bulge was not positioned over and pressed into the grooved flow channel.

Emitter No. 7 (Fig. 6A) with its moving internal steel ball was also designed to operate in an upright position. Initially, the emitters were installed randomly, which resulted in extremely erratic flow rates that were much greater than design flow. Therefore, it was necessary to reposition each emitter upright so that the water pressure-gravity steel ball-flush device operated properly as designed. Although this emitter still failed after 278 days with only screen filtration (Treatments A and B), performance was very efficient with sand and screen filtration (Treatments C through F). The combined emitter clogging rate with these latter treatments was only 4%, the lowest of any system observed (Table IV). Also, the flow rates were further improved by chemically conditioned water (Table V). Flow rates exceeding design flow (Treatment D) were caused by steel ball-flush valves that would not close properly. Only a few emitters from each treatment were microscopically examined, because no emitters were completely clogged. Generally, the observations indicated that chemical conditioning prevented sediment and scale from adhering to the emitter's internal walls and the steel ball (Figs. 6B, 6C, 6D). This enhanced emitter performance and explained why flow rates were benefited by chlorine and acid (Treatments D and E) (Table V).

Emitter No. 8 (Fig. 7A) with only screen filtration (Treatments A and B) also failed after 278 days because of physical clogging. The emitter required sand and screen filtration (Treatments C through F) for efficient operation. The combined results from these treatments had an emitter clogging rate of 21% (Table IV). Also, flow rates were maintained nearer design flows by chemically conditioned water, especially continuous acid (Treatment F) (Table V). Microscopic examination of clogged emitters indicated that the small vortex chamber and flow path diameter (Table I) made the emitter more susceptible to physical clogging (Figs. 7B, 7C, 7D).

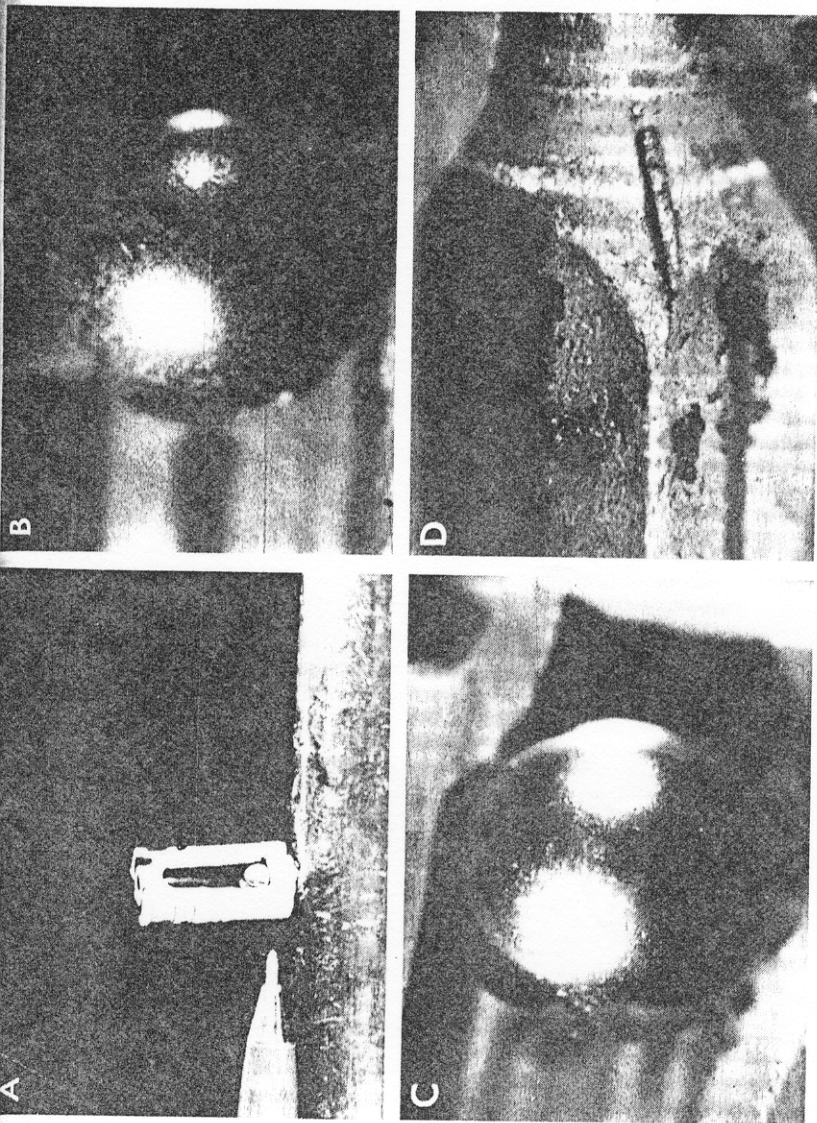


Fig. 6. Emitter 7 with representative clogging problems. A: Automatic steel ball-flush valve emitter on a lateral line. B: Steel ball in emitter receiving unconditioned water (Treatment C) was coated with carbonate scale and residue that reduced flow rates, but the emitter was not clogged. C: Steel ball in emitter receiving continuous acid (Treatment F) had an uncorroded surface, which enhanced emitter performance. D: Internal chamber of emitter in Fig. 6C showing the flow channel. When the steel ball-flush valve was closed, the continuous acid (Treatment F) prevented carbonate scale formation and minimized residue accumulation on the emitter walls.

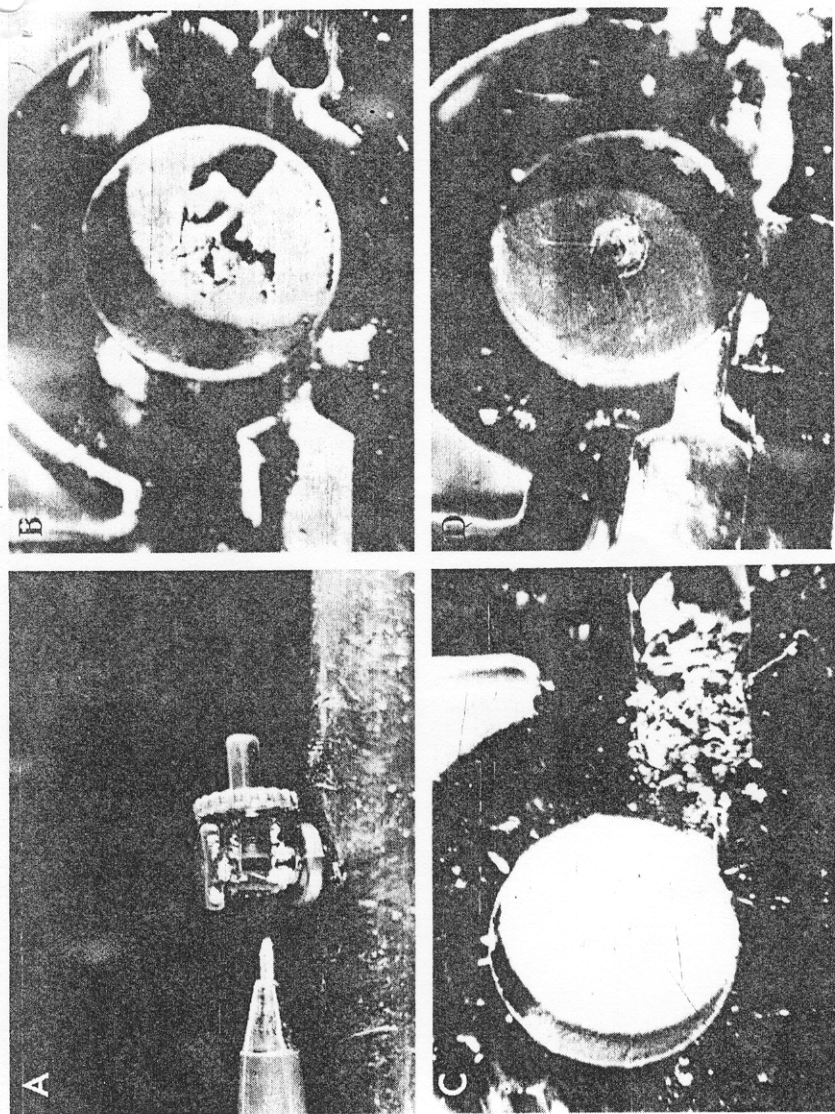


Fig. 7. Emitter 8 with representative clogging problems. A: Single vortex emitter on a lateral line. B: Plastic particles (white PVC) and organic detritus clogged the entrance of the vortex chamber. C: Plastic particles (black polyethylene) and organic detritus clogged the entrance of the vortex chamber. D: The thorax and body of an ant clogged the exit of the vortex chamber.

Causes of clogging

Our results indicated that physical factors were overwhelmingly the dominant cause of emitter clogging. Biological and chemical factors were of secondary importance (Table VII and Figs. 1 through 7). Physical clogging usually occurred quickly. For example, when only screen filtration was used (Treatments A and B) five emitter systems failed in 278 days because of physical clogging. A combination of sand and screen filtration (Treatments C, D, E, and F) helped considerably to prevent clogging. Chemically conditioning the water, especially with continuous acid (Treatment F), provided

TABLE VII

Causes of clogging or flow reduction and relative percent occurrence in trickle irrigation emitter^a

Causes of clogging	Percent of occurrence	
	Individual	Total
<i>Physical factors:</i>		
Sand grain	17	
Plastic particles	26	
Sediment	2	
Body parts of insects and animals	3	
Deformed septa ^b	7	55
<i>Biological factors:</i>		
Microbial slime	11	
Plant roots and algal mats	3	14
<i>Chemical factors:</i>		
Carbonate precipitates	2	
Iron-magnesium precipitates	0	2
<i>Combined factors^c:</i>		
Physical/biological	8	
Physical/chemical	2	
Chemical/biological	6	
Physical/biological/chemical	2	18
<i>Non-detectable (probably physical)</i>	—	11

^aResults are representative of eight emitter systems and four water treatments (C, D, E, and F), which were operated for more than 4 years. There were 1200 emitters installed in these water treatments, and 119 with reduced flow or clogged conditions (< 50% design flow) were dissected and microscopically examined for causes of flow reductions.

^bSilicone rubber discs in Emitter No. 6 were deformed by water treated with chlorine and acid (Treatments D and E), which restricted flow.

^cThe observations indicated that the most likely initial cause of flow reduction was a physical factor, followed by the development of biological and chemical factors. The major physical factors involved were sand grains and plastic particles.

further benefit. However, even with sand and screen filtration, physical clogging with sand grains and plastic particles occurred in 43% of the emitters that were clogged. This indicated that extreme care should be taken during installation to keep lines clean and free of plastic saw shavings and other foreign particles that might dislodge. During installation of our system, after sawing and cutting plastic pipe, we used a reamer and cloth to clean joints before cementing. Then all main, submain, and lateral lines were thoroughly flushed. However, these installation procedures proved to be inadequate. A better cutting tool for large and small diameter plastic pipe might have been helpful. Also, sediment traps or auxiliary in-line screens could be installed after the primary sand and screen filters as protection against a possible failure of a sand or screen filter.

SUMMARY AND CONCLUSIONS

Trickle irrigation experiments with Colorado River water on citrus trees in southwestern Arizona were conducted to develop water treatment methods for prevention of emitter clogging and maintenance of long-term operation of trickle irrigation systems under actual field conditions. Eight trickle emitter systems in combination with six water treatments were evaluated during a comprehensive 4-year study. Flow rates and microscopic examination of emitters were related directly to emitter performance and emitter clogging problems.

Emitter systems that performed efficiently with only screen filtration had a long-path, spiral-grooved, manual flush design (No. 2 and 3). All other emitter systems except the expandable diaphragm design (No. 4) required sand and screen filtration to prevent physical clogging. Chemical treatments further benefited performance by controlling carbonate precipitation and microbial slime development.

The expandable diaphragm emitter (No. 4) never developed clogging problems, but failed because of increased flow rates caused by either reactions with the chemically conditioned water or physical and biological decomposition of the flexible rubber diaphragm. Continuous acid (Treatment F) benefited the performance of this emitter most, but even with this treatment visual and microscopic examination revealed that the rubber diaphragm was in an advanced stage of decomposition and that the emitter flow rates would eventually increase.

We found that the automatic flushing emitters (No. 6 and 7) were more susceptible to malfunction and clogging problems, especially if they were not installed vertically on the lateral lines.

For emitters unaffected by material deterioration, the continuous acid treatment alone was just as effective as a combination of continuous or intermittent chlorine and acid treatments for reducing emitter clogging.

The dominant cause of emitter clogging and flow reduction were physical factors followed by the combined development of biological and chemical

factors, which played a minor role in emitter clogging. The major physical factors involved were sand grains and plastic particles. Therefore, to minimize emitter clogging problems with Colorado River water, adequate filtration for removal of the suspended load would be essential, periodic flushing of lateral emitter lines would be helpful, and extreme care must be taken to avoid introduction of plastic cuttings and sand particles into the lines during installation and repair. In conclusion, our results have shown that successful operation of long-term trickle irrigation systems required that the interdependent effects of both water quality and emitter design be fully considered before making water treatment recommendations.

ACKNOWLEDGEMENT

The work was partially funded by the Bureau of Reclamation. We thank R.L. Roth of the University of Arizona Experiment Station at Yuma for his help in installing and maintaining the trickle irrigation systems and Jacinto Sguirre, Barbara Rasnick, and Jack B. Miller for their technical assistance in the field and laboratory.

REFERENCES

- Bucks, D.A., Nakayama, F.S. and Gilbert, R.G., 1977. Clogging research on drip irrigation. Fourth Annu. Int. Drip Irrig. Assoc. Meet. Proc., Fresno, CA, Oct. 1976, pp. 25-31.
- Bucks, D.A., Nakayama, F.S. and Gilbert, R.G., 1979. Trickle irrigation water quality and preventive maintenance. *Agric. Water Manage.*, 2: 149-162.
- Ford, H.W., 1975a. The use of chlorine in drip irrigation systems. *Florida State Hort. Soc. Proc.*, 88: 1-4.
- Ford, H.W., 1975b. Blockage of drip irrigation filters and emitters by iron-sulfur-bacterial products. *Hortic. Sci.*, 10: 62-64.
- Ford, H.W., 1976. Controlling slimes of sulfur bacteria in drip irrigation systems. *Hortic. Sci.*, 11(2): 133-135.
- Ford, H.W., 1977. The importance of water quality in drip/trickle irrigation systems. *Proc. Int. Soc. Citriculture*, 1: 84-87.
- Ford, H.W., 1979. Characteristics of slime and ochre in drainage and irrigation systems. *Trans. ASAE*, 22: 1093-1096.
- Ford, H.W. and Tucker, D.P.H., 1974. Clogging of drip systems from metabolic products of iron and sulfur bacteria. *Second Int. Drip Irrig. Congr. Proc.*, San Diego, CA, pp. 212-214.
- Ford, H.W. and Tucker, D.P.H., 1975. Blockage of drip irrigation filters and emitters by iron-sulfur bacterial products. *Hortic. Sci.*, 10: 62-64.
- Gilbert, R.G., Nakayama, F.S. and Bucks, D.A., 1979. Trickle irrigation: prevention of clogging. *Trans. ASAE*, 22: 514-519.
- McElhoe, B.A. and Hilton, H.W., 1974. Chemical treatment of drip irrigation water. *Second Int. Drip Irrig. Congr. Proc.*, San Diego, CA, pp. 215-220.
- Nakayama, F.S. and Bucks, D.A., 1980. Clogging effects on emitter discharge rate and trickle irrigation uniformity. *Trans. ASAE*, in press.
- Nakayama, F.S., Bucks, D.A. and French, O.F., 1977. Reclaiming partially clogged trickle emitters. *Trans. ASAE*, 20(2): 278-280.

- Nakayama, F.S., Gilbert, R.G. and Bucks, D.A., 1978. Water treatment in trickle systems. J. Irrig. Drain. Div., ASCE, 104 (IRI): 23-34.
- Pelleg, D., Lahav, N. and Goldberg, D., 1974. Formation of blockages in drip irrigation systems. Second Int. Drip Irrig. Congr. Proc., San Diego, CA, pp. 203-208.
- Solomon, K., 1977. Evaluation criteria for trickle irrigation emission devices. Fourth Annu. Int. Drip Irrig. Assoc. Meet. Proc., Fresno, CA, Oct. 1976, pp. 65-76.
- Wilson, D.L., 1972. Filtration, filters and water treatment. Third Drip Irrig. Seminar Proc., San Diego, CA, pp. 17-23.

