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TRICKLE IRRIGATION WATER QUALITY AND PREVENTIVE MAINTENANCE

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ABSTRACT

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The most serious problem in trickle irrigation is clogging of emitters or applicators. Recommendations and guidelines are presented for preventive maintenance which include water filtration, chemical treatment, pipeline flushing, and field inspection. A suitable type, size, and capacity of a filtration unit is required. Chemical treatment should be considered in terms of theory and field research on the reclamation and prevention of emitter clogging. Proper procedures for the flushing and field inspection of trickle irrigation systems are also essential. Because water quality is of primary importance in the design and operation of this maintenance program, a tentative water-classification system was developed to establish criteria by evaluating the clogging potential of a trickle irrigation water source.

INTRODUCTION

Trickle/drip irrigation is a means of applying water efficiently to plants. Emitter clogging can become a major problem with many systems unless correct preventive measures are taken. Clogging will adversely affect the rate of water application and uniformity of water distribution, and increase operating costs, as it becomes necessary to check, replace, or reclaim bad emitters. However, the greatest loss can be the grower's confidence with the trickle irrigation method. When his confidence is lost, he may abandon trickle irrigation and return to his previous irrigation method.

Trickle irrigation researchers and equipment manufacturers have chosen two approaches to solve the clogging problem. The first is to develop emitter devices which may require less or minimum maintenance (Wilson, 1972; Solomon, 1977). A second approach, which is the subject of this paper, is to focus attention on improving the quality of water before it reaches the emitters (Ford and Tucker, 1974; McElhoe and Hilton, 1974; Ford, 1976; Bucks et al., 1977; Nakayama et al., 1978).

For the purpose of our discussion, a trickle system has the following flow characteristics: discharge rates from single point-source emitters of less than 12 l/h, and line-source emitters of less than 12 l h^{-1} m^{-1} of lateral line. Preventive maintenance will include filtration, chemical treatment, flushing trickle lines, and field inspection.

WATER QUALITY

Primary physical, chemical, and biological contributions to trickle irrigation clogging are summarized in Table I. (1) Physical: suspended inorganic silt-, sand-, and clay-size particles, and organic plant, animal, and bacterial debris, can block or accumulate enough to clog the emitters. (2) Chemical: dissolved chemicals in the water, like calcium carbonate and calcium sulfate at high concentrations, can precipitate out and eventually form encrustations that will restrict water movement. Similar situations can occur when metal hydroxides or sulfides of iron and manganese precipitate out. Some types of fertilizers can react directly with the dissolved material in the water to increase precipitation. (3) Biological: microbial activity can produce slime, filaments, and chemical deposits that can clog emitter passages. These contributors are closely interrelated, and controlling one may also alleviate problems caused by the other. For example, by reducing microbial slime, there is less tendency for the suspended particles in the water to stick on to the slime and agglomerate and build up in the trickle lines and emitters. In addition, some small aquatic organisms such as snail eggs and larva, that are not readily observed and analyzed, can develop into large entities in the trickle lines and impose a combined physical and biological problem.

Presently, there is no proven practical method that will determine whether the user will encounter clogging problems, and, if so, how much and what can be done about it. Generally, municipal waters that have been filtered and chlorinated for controlling disease-causing bacteria are the least troublesome, but treatment of agricultural water to this quality can be impractical and uneconomical.

Table II shows a water-quality classification system that we used to evaluate surface irrigation water for trickle systems. The numerical ratings selected for the physical, chemical, and biological composition were arbitrary, but it gave us a basis for comparing different types of water. With further research, the classification will undoubtedly be improved. Each of the three factors is given a rating of zero to 10. A combined value of "0—0—0" for the water is considered excellent, whereas one of "10—10—10" is poor. Alternately, if the sum of the three factors totals 10 or less, little problem is anticipated, whereas 10 to 20 indicates some problem and 20 to 30 is a severe problem. For the latter two situations, water filtration plus other preventive measures are suggested.

By using such a scheme, we have classified several types of water used in our trickle irrigation studies (Table III). Except for the city water, other

TABLE I

Principal physical, chemical, and biological contributors to clogging of trickle systems

A. Physical: suspended solids	B. Chemical: precipitation	C. Biological: bacteria and algae
1. *Organic*	1. Calcium or magnesium carbonate	1. Filaments
(a) Aquatic plants (phytoplankton /algae)	2. Calcium sulfate	2. Slimes
(b) Aquatic animals (zooplankton)	3. Heavy metal hydroxides, oxides, carbonates, silicates, and sulfides	3. Microbial depositions
(c) Bacteria	4. Fertilizers	(a) Iron
2. *Inorganic*	(a) Phosphate	(b) Sulfur
(a) Sand	(b) Aqueous ammonia	(c) Manganese
(b) Silt	(c) Iron, zinc, copper, manganese	
(c) Clay		

TABLE II

System for classifying irrigation waters used in trickle systems

Arbitrary rating	Physical	Chemical* (max. mg/l		Biological
	Suspended solids (max. mg/l)	Dissolved** solids	Iron and/or manganese	Bacteria*** populations (max. no./ml)
0	< 10	< 100	< 0.1	< 100
1	20	200	0.2	1000
2	30	300	0.3	2000
3	40	400	0.4	3000
4	50	500	0.5	4000
5	60	600	0.6	5000
6	80	800	0.7	10000
7	100	1000	0.8	20000
8	120	1200	0.9	30000
9	140	1400	1.0	40000
10	>160	>1600	> 1.1	>50000

*Tentative chemical classification is based on the highest rating for either dissolved solids, soluble iron, or manganese.
**If water pH is 7.5 or greater, rating is increased by 2.
*** If water is known to contain an abundant reproductive snail population, rating is increased by 4. Bacteria populations do reflect increased algae and microbial nutrients.

irrigation waters require more than minimum water treatment including filtration. Water source No. 2 with its high suspended load needed special water filtration. This was not initially chemically treated; and after 2 years of operation, chemical treatment was required to reclaim and prevent further clogging (Nakayama et al., 1977). Water sources No. 3 and No. 4 were used with various filtration and chemical treatments in which the clogging process is being closely monitored (Bucks et al., 1977; Nakayama et al., 1978).

The timing of water sampling is important, particularly in situations where there are large fluctuations in water quality during the irrigation cycle. Water quality may be classified good at some and poor at other times of the year.

FILTRATION

A good filtration system is an essential component of a trickle system. Filters remove unwanted physical contaminants, which include suspended or undissolved organic and inorganic materials. Suitable filters include pressure filters (screen, centrifugal, and media, i.e., sand or gravel packs) and gravity filters (primarily settling or sediment basins). In selecting the type, size, and capacity of the filtration units, the primary factors to be considered are the initial water quality and emitter design.

TABLE III

Classification of four waters used in trickle experiments

Type of source	Physical	Chemical (max. mg/ml)		Biological	Water classification
	Suspended* solids (max. mg/l)	Dissolved solids	Iron or manganese	Bacteria* populations (max. no./ml)	(phys.—chem.—biol.)
1. City water	< 1	500	0.05	< 10	0— 4—0
2. Runoff water	300	50	0.05	10000	10— 0—6
3. River water	70	900	0.10	4000	6— 8—4
4. Well water	1	1650	0.05	40000	0—10—9

*Values of suspended solids and microbial populations varied considerably over the sampling period, and the worst situation was used in this case.

TABLE IV

Soil particle size equivalents in microns and screen mesh numbers

Soil particle size	Microns	Screen mesh number
Very coarse sand	1000—2000	18—10
Coarse sand	500—1000	35—18
Medium sand	250—500	60—35
Fine sand	100—250	160—60
Very fine sand	50—100	270—160
Silt	2—50	—
Clay	< 2	—

Screen filters, made of metal, plastic, or synthetic-cloth and enclosed in a special housing, are the simplest. Aquatic algae in the water tend to cause screen blockage and can reduce the filtering capacity. Most manufacturers recommend 100- or 200-mesh (150- or 75-micron) screen filter, with a few recommending a coarse screen of 30 mesh (600 microns).

Media filters consist of fine gravel and sand of selected sizes placed in a pressurized tank. Since media filters are not easily plugged by algae, they can remove relatively large amounts of suspended solids before clogging. However, media filters can provide conditions favorable for increased bacterial growth. Media filters that are presently used will retain particle sizes in the range of about 25 to 100 microns. Water flow through the filters should not exceed 800 $l\ min^{-1}\ m^{-2}$ of filtration surface area, and the filtration media should be at least 45 cm thick. Media filters can be followed by a secondary filter or a rinse-away valve to prevent possible contaminants from going beyond the sand filter during the backwashing process.

Sand separators, hydrocyclones, or centrifugal filters remove suspended particles that have a specific gravity heavier than water and that are larger than 75 microns, but these filters are ineffective in removing most organic solids. A sand separator can effectively remove a large amount of sand particles and sometimes be installed on the suction side of the pump as a prefilter to reduce pump wear.

Settling basins, ponds, or reservoirs can remove large volumes of sand and silt; but unless these have protective covering, the water is exposed to windblown contamination and subject to algae growth that should be controlled by commercially available algicides. Thus, these structures are normally not used for water sources from wells.

As for size or degree of filtration, the designer and user are concerned with the largest sized particles which will pass the filter. Table IV shows the equivalent micron sizes and screen mesh numbers for various sizes of soil particles (Wilson, 1972). A 200-mesh screen, or a 75-micron cartridge, sand, and centrifugal filter, will filter out only a part of the very fine sand. An analysis of the particle-size distribution for the materials in the unfiltered water can help in determining the optimum degree of filtration. If, for example, the particle-size distribution for suspended materials in water source No. 3 was about 60% sand, 30% silt, and 10% clay, a 50-mesh screen should remove less than 25% of the sediment, whereas a 200-mesh (75-micron) screen would remove at least 50% of the sediment. Therefore, the latter choice would be better for most trickle systems using this water.

The emitter sensitivity to clogging should also be considered before choosing a filtration system. When available, we should follow the recommendations of the trickle irrigation manufacturers on the degree of filtration required. If this is not available, however, filtration at a size of one-tenth the diameter of the emitters' smallest opening may be used. This is to prevent the possibility for the grouping or bridging of particles and the tendency of inorganic particles to settle out or deposit in the emitter.

The filter capacity (total surface area) should be sufficiently large to permit the rated flow of filter water without frequent cleaning of the filter. The maximum recommended allowable pressure loss across the filter is about 69 kPa before filter cleaning is required. Automatic backwashing filters are available, but filters that are to be cleaned by hand should not require more than daily maintenance. As a general rule, filtration units should be designed with at least a 20 to 30% extra capacity, since water qualities may fluctuate during the irrigation period. Pump sizes should also be increased accordingly to provide some reserve operating pressure and capacity for backwashing of filters and flushing of trickle lines.

CHEMICAL TREATMENT

Theory

When irrigation water have pH's above 7.5 and high calcium or magnesium contents or water hardness, calcium or magnesium carbonate can precipitate out either in the filter, tubing, or emitter. Adding acid to the water will lower the pH and reduce chemical precipitates. Fig. 1 shows that about 0.4 meq/l of sulfuric acid is needed to maintain a pH of 7 for water source No. 3. Since stock technical grade sulfuric acid contains 34 000 meq/l, about 1 l of sulfuric acid is required for every 85 000 l of water delivered by the trickle system.

The pH control is also important for bacterial control. Fig. 2 shows that hypochlorous acid, the active component in chlorination, is more abundant at the lower pH values (White, 1972), which means that bacteria control is more effective at lower pH's. However, lowering the water pH continuously below 6.0 can cause corrosion problems. Also, sodium hypochlorite (laundry bleach) or calcium hypochlorite is alkaline and will increase the water's pH (decrease acidity), necessitating the addition of an acid source.

Chlorine gas, unlike calcium or sodium hypochlorite, has an acid reaction with water. The amount of acidity produced depends upon the water quality,

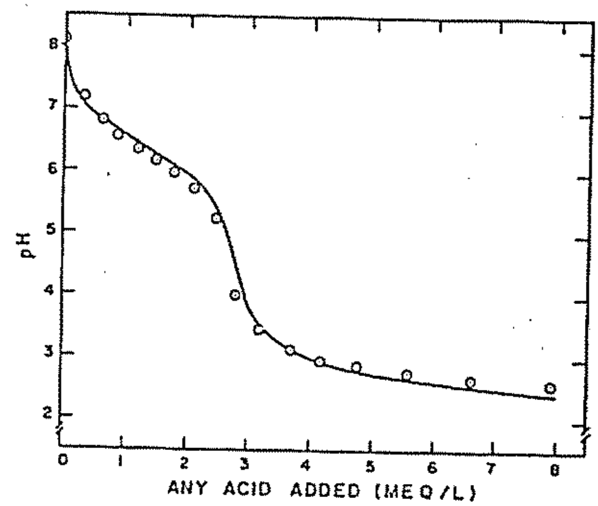

Fig. 1. A titration curve showing the effects of acid addition on the pH of water source No. 3.

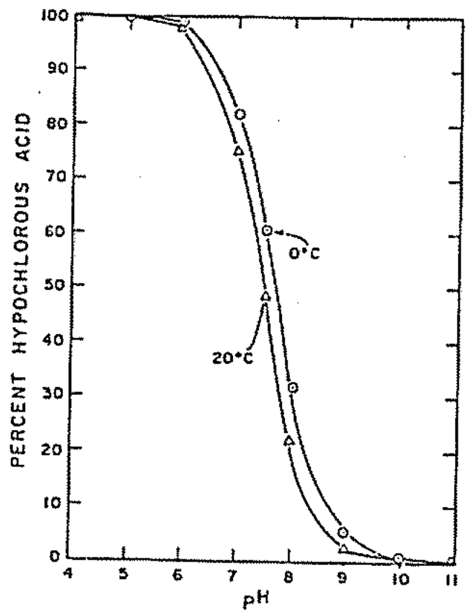

Fig. 2. Relationship between the amount of hypochlorous acid in solution and pH (White, 1972).

the amount of chlorine added to the water, and whether the system is "closed" or "open" to the atmosphere. With water source No. 2, 10 mg/l chlorine and a "closed" system can decrease the pH from about 8.2 to 7.0. Thus, an additional acid source is normally not needed along with gaseous chlorine. Chlorination for bacterial control is not recommended when water has 0.4

mg/l or more dissolved iron, because chemical reaction will form iron oxide which can precipitate and cause blockages of emitters (Ford and Tucker, 1974).

Some of the alternative chemicals to control bacteria and algae are xylene permanganate, ozone, quaternary ammonium salts, copper salts, acrolein, hydrogen peroxide, bromine, and iodine. All these chemicals may not be for practical use. Xylene and permanganate are too costly or may be toxic to the plants. Ozone is a good bactericide but has no residual effect in the pipelines. Quaternary ammonium salts also kill bacteria and even snails, but they are expensive. Copper salts have been used widely as an algicide. Acrolein is being used more in California and Florida, but it is difficult to handle, and we do not know its chemical behavior on plants. Other bactericides, like hydrogen peroxide, bromine, and iodine, have been reported to be used, but again these have not proven to be entirely satisfactory in normal field applications.

Reclamation

As noted earlier, untreated water source No. 2 caused plugging after the second year of operation. Manual flushable emitters were installed on a management study for table-grape production, as described by Bucks et al. (1974). We found that these emitters could be reclaimed by treating the system for about 24 h with high chlorine and acid (100 mg/l Cl at a pH of

TABLE V

Emitter flow rates before and after reclamation by chemical treatment and flushing of water source No. 2

Irrigation unit	No. of emitters	Design flow (l/h)	Emitter flow rate (l/h)	
			Before treatment*	After treatment**
T-1	72	3.8	2.2	3.6
T-2	144	3.8	2.6	3.2
T-3	144	3.8	2.7	3.7
T-4	144	3.8	1.9	3.6
T-5	72	3.8	2.1	3.3
T-6	144	3.8	2.5	3.5
T-7	144	3.8	3.1	3.5
T-8	144	3.8	2.7	3.5
T-9	72	3.8	2.2	3.6
T-10	144	3.8	2.5	3.6
T-11	144	3.8	2.8	3.5
T-12	144	3.8	2.6	3.5

*Average flow rate for 3 months of operation before treatment.
**Average flow rate for at least 22 months of operation after treatment.

2). Twelve partially clogged, irrigation units were treated in this manner, and the emitter flow rates were increased from as much as 50% to approximately 90 to 95% of design, as shown in Table V (Nakayama et al., 1977). The original slug treatment for reclamation was followed by continuous 1 mg/l chlorine at a pH of 7, which helped to maintain the system operational for 3 years remaining in the investigation.

Prevention

In January 1975, a long-term research study on the prevention of emitter clogging by chemical treatment was initiated (Bucks et al., 1977; Nakayama et al., 1978). Water source No. 3 was treated in six ways before being delivered to eight different emitter systems that were used to irrigate mature citrus trees. The treatments were: (A) screen filtration alone (50 mesh); (B) screen filtration (50 mesh) and intermittent chlorine and acid; (C) sand (20 silica) and screen (200 mesh); (D) same as (C) plus intermittent chlorine and acid; (E) same as (C) plus continuous chlorine and acid; and (F) same as (C) plus continuous acid. The intermittent treatment (B) and (D) consisted of 10 mg/l equivalent chlorine and sulfuric acid to adjust the water pH to 7; both were added only during the last hour of an irrigation cycle. The continuous treatment (E) was 1 mg/l chlorine and acid at a pH of 7 for the entire irrigation cycle.

Fig. 3 shows that treatment (E) with continuous chlorine, acid, and sand filtration maintained the cleanest lateral lines. Also, most of the emitter sys-

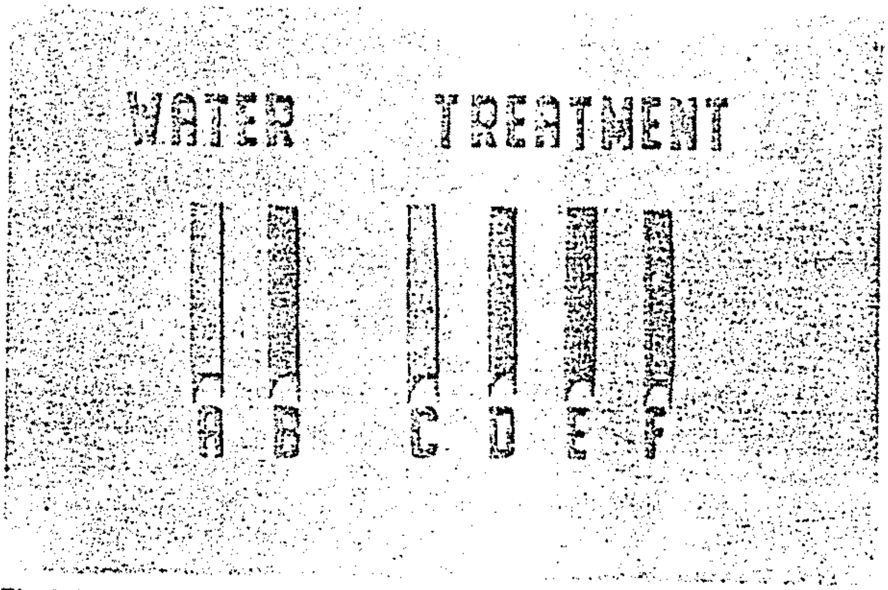

Fig. 3. Effect of various water treatments (water source No. 3) on material deposition in lateral emitter line.

tems have operated well under this treatment. There were differences in the reliability of the eight emitter systems, and several of them performed quite satisfactorily with adequate filtration alone. However, for long-term operation, it seems that many of the emitter systems using a similar or lower quality water will require some chemical treatment.

Operation

No matter what chemical is used — fertilizer, insecticide, herbicide, acid, or bactericide — the material should not damage any component of the trickle system. Plastic manufacturers and distributors have put out compatibility tables listing the chemical resistance of the various products. Generally, the concentration of chemicals to be injected into the system is normally very low, ranging from 4 to 100 mg/l for fertilizers and 0.5 to 10 mg/l for bactericides. Acids and bactericide concentrations in waters should be routinely monitored after the filters and at the end of the lateral lines to check if the entire trickle system is being treated.

Chemical injectors should be equipped with an antisiphon valve to prevent the water supply from getting into the stock chemical tanks and overfilling concentrated chemicals to the surrounding area. If electrical injectors are used, a pressure or flow control switch should be installed so that chemical injection stops when the rate of water flow to the field is drastically reduced. Also, a backflow or vacuum breaker valve is often placed after the filters to prevent the backflow of water from the main pipelines to the pump. Where municipal water is tied to the irrigation system, a backflow valve should be required.

FLUSHING TRICKLE SYSTEM

To minimize sediment buildup in trickle systems, growers and researchers have recommended regular flushing of trickle pipelines (Shearer, 1977). Because of the varied water qualities, management practices, trickle emitter systems, and limited research trials, line flushing may not always be required. However, valves should be provided at the ends of mains and submains and provisions made for flushing of lateral lines. Furthermore, connections to lateral lines should have large enough diameters to facilitate flushing.

Automatic flushing of lateral lines can be done at the beginning and at the end of each irrigation cycle. Problems have occurred in the operation of some automatic-flushing devices, but some of the newer valves may ensure adequate flushing. Mains and submains can also be flushed automatically, by use of an electric or battery-time-operated, normally closed valve. Automatic flushing will be more beneficial where the water is extremely high in silt and clay content.

Periodic hand flushing of trickle lines can also be used. Operators should begin with the flushing mains and proceed to the submains and laterals.

TABLE VI

Flushing effects on sediment and iron accumulation in lateral emitter lines for various water source No. 3 treatments

Date	Sediment (mg/cm)					Iron (mg/l)				
	A	C	D	E	F	A	C	D	E	F*
24 May 1976**	5.0	3.1	2.7	2.6	4.6	0.60	0.24	0.40	0.88	1.00
28 Jun 1976	6.0	3.5	1.0	1.0	1.8	0.98	0.45	0.93	0.28	0.73
19 Aug 1976	28.2	7.6	2.4	5.0	5.0	1.34	1.50	0.75	0.50	1.10
15 Nov 1976***	1.5	1.4	1.5	0.8	1.1	0.03	0.20	0.22	0.39	0.25

*Filtration and chemical treatments are listed in the text.
**All lines flushed 30 March 1976.
***All lines flushed 23 October 1976.

The flush water will run clear, followed by high-sediment water, and then again clear. There is no dependable check to ensure complete flushing, but clean, filtered water should run at least 2 min before hand valves are closed. A general recommendation for flushing would be every 6 months for tree crops and at the beginning, the middle, and the end of each season for row crops. When the system is initially installed, operators may wish to flush more frequently. With water source No. 3, used in our chemical treatment for prevention of emitter clogging experiment, we have been hand flushing trickle lines about once during the winter and twice during the summer. Table VI shows how flushing of submains and laterals has controlled the buildup of sediment and iron.

An extra flow capacity of at least 20 to 30% for pump and filter units was previously suggested to provide for adequate filtration at all times. This additional capacity is also of assistance in flushing trickle lines. Normally, only a few trickle lines can be hand flushed at one time; and with automatic flushing valves, the system must often be divided into smaller subunits. This is to provide for a flow velocity greater than 18 m/min during the flushing process.

FIELD INSPECTION

Systematic inspection of a trickle system is required to spot malfunctioning emitters, pipeline leaks, and accessory equipment failures. Some of the field inspection can be done when the crop is being checked.

Good maintenance requires that filtration and chemical injection units be kept in perfect operating condition. Screen, media, and centrifugal filters must be cleaned periodically, either automatically or manually. Operation of filters, chemical injectors, time clocks, pressure regulators, water meters, and the pump must also be checked routinely and repairs made according to manufacturer's recommendations.

All trickle systems should be provided with a flow meter to aid in sceduling irrigations. Flow metering is also useful to indicate either inadequate pressure regulation, pipeline leaks, or emitter clogging. Most flow meters give the accumulated flow, and operating times must be known to estimate the rate of flow. Even if a rate meter is used, the accumulated flow over a specific period of time often gives more accurate results. Visual checking for malfunctioning emitters and pipeline leaks will still be required at least every month.

SUMMARY

Reliability in the performance of a trickle irrigation system depends upon preventive maintenance. Preventive maintenance must include proper water filtration and field inspection, and sometimes chemical treatment and pipeline flushing. Because water quality is of primary importance in design

and operation of this maintenance program, a tentative water-classification system was developed to establish criteria for evaluating the clogging potential of a trickle irrigation water supply.

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