exposed to root phytotoxins and root-rot diseases.

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Controlling Slimes of Sulfur Bacteria in Drip Irrigation Systems[1]

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Additional index words. Beggiatoa, Thiothrix, Vitreoscilla, chlorine

Abstract. **A white sulfur slime produced by certain sulfur bacteria clogged drip irrigation emitters when the water contained H_2S. Systems were cleaned by irrigating continuously for 3 weeks after first eliminating O_2 leaks. After cleanout, growths of sulfur bacteria were prevented by keeping the lines full of water and free of O_2 between irrigations. Intermittent injection of chlorine to yield a free residual level of 0.5 ppm prevented sulfur bacterial growths. Lowering the pH to 6.4 with SO_2 or 6.0 with HCl also inhibited sulfur bacterial growths.**

Drip irrigation is being used extensively for horticultural crops in the U.S. and elsewhere particularly in arid regions where water may be at a premium. Restrictions on water utilization by regulatory boards has spurred interest in drip irrigation. The small emitter orifices employed in such systems are subject to clogging, so that the quality of water used for drip irrigation is of paramount importance. The initial indiscriminate use of drip installations in Florida resulted in the discovery of a diversity of new clogging problems. The fundamentals, associated particularly with Fe and S, and preliminary attempts at control have been described by Ford (4). Particulate matter and carbonate clogging of emitter orifices have been reported from several areas of the world (7, 8, 9, 10). Microbiological deposits (4, 7, 8, 10) have only recently been reported in the literature. The need for water quality measurements geared specifically to drip irrigation sludge problems has been outlined (3).

In well water sources containing H_2S and traces of O_2, a white gelatinous sulfur slime can occur in emitters and filters. The filamentous sulfur bacteria, *Thiothrix* sp., predominately *Thiothrix nivea* (Robenhorst), was found to be the principal clogging agent in Florida. Filaments of *Thiothrix* and to a lesser extent *Beggiatoa* sp., coated and stuffed with elemental S, formed a massive matted block (4). A nonsulfur filamentous bacterium *Vitreoscilla* has recently been isolated. It contributes to clogging by its voluminous mass.

Most deep wells in south Florida are usually artesian with 1 to 5 ppm total sulfides and $<$0.2 ppm of Fe, unless well casings are severely corroded. The waters are usually deficient in such clogging agents as particulate matter and suspended solids.

Thiothrix nivea, the predominate sulfur oxidizing bacterium, has been found by the author in locations where well water contained $<$0.2 ppm of total sulfides and a min of 0.05 ppm of O_2. Although *Thiothrix* has been considered to be an autotrophic sulfur organism (6), the author has found considerable quantities of Fe (detected by staining with Prussian blue) accumulating in the filamentous stalks. When this has occurred, *Thiothrix* contributed to a mixed sludge problem of Fe and S in drip irrigation systems. In all installations studied in Florida, the organism has not survived in the absence of O_2 (4) as determined by iodometric methods (1). The possible role of CO_2 was not investigated. *Thiothrix* was suspected of having a restricted pH range because it has not been found in natural acid spring waters containing H_2S (6). One drip irrigation site yielded water containing 0.7 ppm of H_2S and 0.5 ppm of Fe at a pH of 6.3. After 2 years of irrigation, only traces of *Thiothrix* and sulfur slime were found even though O_2 was detected. Practically all deep artesian wells in central and south Florida yield waters with a pH $>$7.0.

Studies were conducted to develop practical procedures involving biological and chemical methods to clean out and maintain drip irrigation systems. Only the successful methods are reported in this paper.

Four groves were selected to evaluate the most promising biological procedures for removing sulfur slimes that had accumulated in lines and emitters. *Thiothrix* had developed in each system and O_2 was present from leaks. The leaks were corrected and the irrigation systems run continuously for 3 to 4 weeks. White sulfur slimes occurred on the outsides of emitters while slimes gradually disappeared from inside lines and emitters and were eliminated in 19 to 25 days. It is suggested that the slimes may have been digested by sulfate reducing organisms. It is known that sulfate reducing organisms, such as *Desulfovibrio*, can utilize S to form H_2S (2). Perhaps the organic matrix of the sludge could serve as the energy source. *Desulfovibrio* was cultured from artesian water sources.

After the biological cleanout treatment, 2 mechanical methods and 1 chemical procedure were used successfully to prevent bacterial growths for those irrigation systems that were on level ground and free of air leaks. In the first study, the check valve between

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the centrifugal pump and the artesian well was removed. The natural artesian water pressure and flow from the well was sufficient to keep the lines full during that period when the irrigation system was not in operation (Table 1). The flow rate from the last emitter in one typical test site was 1 ml/min whereas during irrigation it was 72 ml/min. No O_2 or *Thiothrix* filaments were detected in the lines.

In the second study, located on level ground, several blocks of citrus were irrigated from a single deep sulfide laden well. The turbine pump operated continuously during the irrigation season. When a particular block was not being irrigated, a line valve was "cracked" just enough to keep emitters full (Table 1). No O_2 entered the system as indicated by tests for dissolved O_2. No *Thiothrix* organisms were found after 6 months of irrigation. The initial block of the system had been clogged with *Thiothrix* from the use of a shallow well. The lines were cleaned by 3 weeks of continuous irrigation from the new well before the additional blocks were placed in operation.

The third study, for installations not on level ground, utilized chlorine injected as NaOCl (sodium hypochloride sol.) near the completion of each irrigation cycle. Chlorine inhibited *Thiothrix* at a free chlorine residual concn of 0.5 ppm based on the ability of functional *Thiothrix* bacteria to adhere to glass slides. Chlorine oxidized H_2S in B.O.D. bottles in <15 sec; however, 9 ± 0.4 ppm of NaOCl was required to oxidize 1 ppm of total sulfides and leave a min of 0.5 ppm of free residual chlorine to inhibit bacteria. This is in agreement with Griffin et al. (5) who reported similar values for potable water systems. Thus a water source with 3 ppm sulfides required 27 ppm NaOCl. The price would be \$.15 per hr/ha – a costly rate for continuous treatment in systems operating 8 to 12 hr for each irrigation cycle.

Table 1. Improvement in flow rates of labyrinth type emitters by eliminating O_2.

	% flow compared to new emitters			
	Continuous irrigation		Intermittent irrigation	
Treatment	1 day[z]	3 weeks[y]	6 months	12 months
Artesian pressure[x]	24	88	96	93
Control valve[x]	13	85	94	97
1 hr NaOCl[w]	–	92	96	–

[z]Clogged emitters were hand flushed to induce some flow.

[y]All emitters hand flushed before intermittent irrigation.

[x]Method for keeping lines full, between irrigation cycles, during intermittent irrigation.

[w]1.0 ppm as free residual Cl injected near completion of each irrigation cycle.

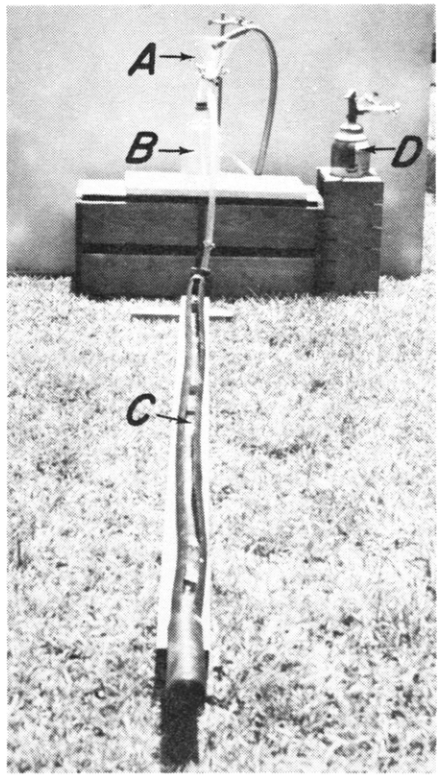

Fig. 1. A model apparatus for promoting and controlling sulfur bacteria and sulfur slime: (A) air-water mix funnel, (B) gas-water mix chamber, (C) slime growth tube, and (D) SO_2 or Cl_2.

Two irrigation systems were used to inject NaOCl at 10 ppm for each ppm of total sulfides, near the completion of irrigation cycles, to evaluate the use of intermittent chlorine injection. The injection time was 1 hr for an 18 ha grove containing 12,000 emitters and a pumping capacity of 530 lpm (Table 1). The 10 ppm rate of injection yielded >1.0 ppm of free residual chlorine at the last emitter on the line. After the first injection, the rate was reduced and adjusted to yield a residual of 1.0 ppm at the last emitter. Thirty min after the irrigation system shut down, the free chlorine content was 0.5 ± 0.2 ppm. No *Thiothrix* filaments were found in the 2 systems using intermittent chlorine injection. Free residual chlorine was measured with a DPD (N,N-diethyl-p-phenylenediamine) type test kit and sulfides by the methylene blue visual color-matching method (1).

An apparatus for growing sulfur oxidizing bacteria and for precipitation of sulfur slimes is shown in Fig. 1. Water with 2.8 ppm total sulfides at pH 7.6 from an artesian well flowed through funnels that permitted O_2 to enter the system. SO_2 and HCl treatments were injected on a continuous basis into the containers at the base of the funnels. Treated water entered the 2.4 m long, 5 cm diam corrugated plastic lines where small quantities of soil and plant

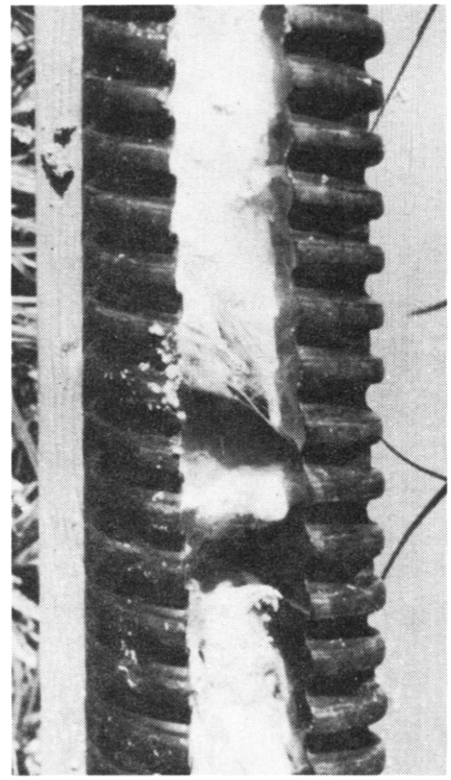

Fig. 2. The growth of sulfur slime in 48 hr in the 5 cm diam corrugated polyethylene slime growth tube.

debris containing sulfur bacteria helped to promote the growth of sulfur slime. Maintaining a pH of 6.0 with HCl inhibited slime formation for 2 weeks but not for 3 weeks. No *Thiothrix* formed in the slime that developed. The organisms were sulfur bacteria not found in drip irrigation lines. A pH of 6.4 with SO_2 (90 ppm SO_3) inhibited all slime formation during treatment; however, elemental S was deposited in the incubation line. Sulfur slime formed in untreated lines within 48 hr (Fig. 2) and *Thiothrix* was identified (Fig. 3). A continuous SO_2 treatment has not been evaluated on a commercial scale and, at

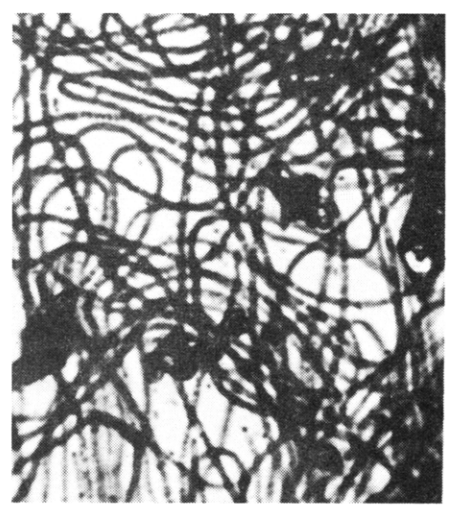

Fig. 3. *Thiothrix* sp. in sulfur slime from the model apparatus designed to promote growths of slime.

present, would be 21 times the cost of intermittent chlorine. A continuous HCl treatment would be 10 to 25 times more expensive than an intermittent chlorine treatment.

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Multiple Cropping with Trickle Irrigation[1]

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Abstract. **Pepper (*Capsicum frutescens* L.) and summer squash (*Cucurbita pepo* var. *melopepo* (L.) Alef.) were grown in immediate succession in undisturbed beds using trickle irrigation with various treatments. Highest combined yield in metric tons/ha for both crops was obtained with film mulch + soil fumigation (117.6) followed by film mulch (112.3), soil fumigation (93.4) and control (69.0), respectively. Yield from the second crop was negatively correlated (r=–.87) with the degree of plant infection with root-knot nematode (*Meloidogyne incognita* (Kofoid & White) Chitwood). Intensive production in this manner allows fixed costs to be defrayed over two crops thus increasing the magnitude of return per dollar invested. Multiple cropping of pepper and squash with trickle irrigation has an excellent potential in south Georgia provided nematodes and other soil-borne pathogens can be adequately controlled.**

Use of trickle irrigation for high value row crops has increased dramatically in the southeastern U. S. in the past 2 years[2]. Its use, especially in conjunction with soil fumigation and film mulch, has resulted in remarkable yield increases for vegetable crops such as pepper, tomato, cucumber, squash and pole bean. Because of the high initial costs of film mulch and soil fumigation, considerable interest has been displayed in the possibility of multiple cropping, growing a second crop immediately after the first. While double cropping has been successful with film mulch and overhead irrigation (1,2), the technique has been little explored with trickle irrigation. Trickle irrigation has the additional advantage of allowing the frequent application of low levels of soluble nutrients to the root zone under the film mulch. This study was directed toward determining the potential of multiple cropping with trickle irrigation and ascertaining possible production problems.

Crop 1 Pepper transplants, cv. Hungarian Hot Yellow Wax, were field planted May 15, 1974 in a Tifton loamy sand. Beds, 9.1 x 1.6 m, were planted with transplants 30 cm apart in the row, with 2 rows 40 cm apart on each bed. Irrigation water and a majority of the N and K fertilizer was applied through 2 Bi-Wall[2] trickle lines per bed. The lines were placed 15 cm from the plants, parallel to the rows, and 13 cm from the edge of the beds. Treatments included with and without 2 mil aluminum-coated film plastic over the beds and with and without a broad-spectrum soil fumigant in all possible combinations with 4 replications. DD-MENCS[3] (Vorlex) was applied at 327 liters/ha through 5 chisels 22.5 cm apart, 20 cm below the soil surface. Prior to fumigation all plots received 550 kg/ha 10N–4.3P–8.3K and 146 kg/ha P broadcast and rototilled into the top 15 cm of soil. Additional N and K was applied through the trickle lines at each irrigation at the rate of 2.8 kg N and 3.3 kg K/ha/day for the first 20 days after transplanting and 5.0 kg N and 5.1 kg K/ha/day for the remaining 60 days.

The final pepper harvest was made August 5, 1974 after which the plants were decapitated just above the plastic and removed.

Crop 2 'Dixie Hybrid' summer squash was direct seeded (3 seeds/hole) Aug. 6, 1974 through the same holes in the plastic that the pepper had been planted. On beds without plastic, seeds were placed directly adjacent to the stumps of decapitated pepper plants. Fertilizer was applied through the trickle lines at each irrigation at the rate of 3.6 kg N and 3.5 kg K/ha/day. A root-gall index was taken from plants near the end of each bed, 16 days after seeding and at the end of the season. Individual plants were rated on a 1-5 scale (1 = no galling, 2 = 1-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-100% roots galled). Soil samples (20 cores, 2.1 x 20 cm) were also collected for nematode assay. Soil samples were mixed thoroughly and a 150 cc aliquot was processed by a centrifugation-flotation method (6) to separate nematodes from the soil.

Film mulch alone produced the highest yield in the initial crop, followed by film mulch with soil fumigation, soil fumigation and control (Table 1). DD-MENCS typically produces some initial stunting of transplants (3, 4); however, in soils with moderate to severe nematode and/or soil-borne plant pathogen pressure, this treatment will often produce a substantially higher final yield than film mulch alone. The results indicate (Fig. 1) that with the initial crop (as reflected by population at the beginning of the second crop), nematode pressure was not severe, which would account in part for the

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[2]Based on information supplied by E. I du Pont de Nemours and Co., manufacturers of Viaflo trickle tube and Reed Irrigation Systems, manufacturers of Anjac Bi-Wall trickle tubing. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture nor imply its approval to the exclusion of other products that may also be suitable.

[3]20% methylisothiocyanate + 80% chlorinated C_3 hydrocarbons; NOR-AM Chemical Co.