Injection of Electrolytically Generated Chlorine into Citrus Microirrigation Systems for the Control of Certain Waterborne Root Pathogens

N. M. GRECH, Graduate Student and Senior Research Pathologist, Citrus and Subtropical Fruit Research Institute, Nelspruit, 1200, and F. H. J. RIJKENBERG, Professor, Department of Microbiology and Plant Pathology, University of Natal, Pietermaritzburg

ABSTRACT

Grech, N. M., and Rijkenberg, F. H. J. 1992. Injection of electrolytically generated chlorine into citrus microirrigation systems for the control of certain waterborne root pathogens. Plant Dis. 76:457-461.

Electrolytically generated chlorine was injected into citrus microirrigation systems. Propagules of *Phytophthora nicotianae* var. *parasitica*, *P. citrophthora*, *Fusarium* spp., algae, and slime-forming bacteria were killed. Nematodes were found to resist free-chlorine levels in water of up to 50 $\mu g\ ml^{-1}$. Microemitters delivering chlorinated water were less frequently blocked by bacterial and/or bacterial slime than those delivering unchlorinated water. Soil and root populations of *Phytophthora* and nematodes under citrus trees in the field were unaffected by chlorinated water. No chlorine-induced phytotoxicity was observed on field-grown plants. In glasshouse studies, treatment levels between 200 and 500 $\mu g\ ml^{-1}$ significantly reduced propagules of *Phytophthora* in the soil and, in some cases, eradicated the pathogen.

Additional keywords: pathogen control, water treatment

Citrus feeder root rot and collar rot, caused by two species of *Phytophthora* (*P. nicotianae* Breda de Haan var. *parasitica* (Dastur) G. M. Waterhouse and *P. citrophthora* (R. E. Sm. & E. H. Sm.) Leonian), is a serious disease of citrus in South Africa (13). Feeder root rot frequently is a problem in the nursery and it can be transferred from there into the field. This results in tree decline, reduced yield and fruit size, and, eventually, tree death.

Although chemical control of citrus feeder root rot in the field with fosetyl-Al and metalaxyl is effective, it also is expensive. Over the last few years, the emphasis has shifted to the production of nursery trees free of *Phytophthora* spp. by preventive phytosanitary methods such as soil fumigation, treated irrigation water, and sound hygiene (17). Once planted out, healthy nursery trees grow consistently better than nursery trees infected with *Phytophthora* (18). However, nursery plants that are initially certified disease-free and planted in virgin soil eventually become infected by irrigation water sources, which frequently are contaminated by *Phytophthora* spp. and nematodes (15). This situation is exacerbated by the widespread use of susceptible rootstocks, such as the rough lemon (13). Also, irrigation water drawn from contaminated sources supplements existing *Phytophthora* and nematode populations in the soil, making chemical control more difficult.

Until recently, the commercial treatment of irrigation water for the elimination of citrus root pathogens was not economically justifiable because of the

The use of a trademark is without prejudice.

Accepted for publication 25 June 1991.

high costs involved. However, an improved electrolytic method of chlorine gas generation has been developed that reduces the cost of chlorination dramatically. Chlorination used as a method of water purification is well documented, particularly in domestic water treatment (21). The use of chlorine in agriculture has, until recently, been restricted to the treatment of water in the nursery and the packhouse (7), primarily for the elimination of pathogens (17). Chlorine in field irrigation systems has, in the past, been used solely as a means of maintaining unblocked emitters (7,11,19). In these applications, it is reported that bacterial slimes and algal growth are suppressed (5,12). This study investigated the effect of chlorination of citrus irrigation supplies on waterborne microorganisms with particular reference to citrus root pathogens and the citrus nematode, *Tylenchulus semipenetrans* Cobb (De Villiers & Milne).

MATERIALS AND METHODS

Source and condition of irrigation water. Irrigation water was drawn from the Crocodile River and pumped into a holding dam. This water source had previously been shown to be highly infested with propagules of *Phytophthora* and the citrus nematode (15). The experiments were conducted during the summer months when there was a heavy load of suspended solids in the water. Initially, five 100-L samples of dam water were passed through a series of sieves for nematode assessment. The mesh dimensions of the sieves were 53, 45, and 38 μm. The material retained by the 38-μm filters was collected by washing with 10 ml of sterile distilled water. The nematodes then were counted under a stereomicroscope.

Similarly, 20 1-L samples were collected from the dam on five separate occasions during the season to assess the *Phytophthora*, *Fusarium*, bacterial, algal, and protozoan population levels. *Phytophthora* propagule levels were determined in the laboratory by filtering 10 1-L water samples, first by gravity through a No. 1 Whatman filter and then by suction through a 2-μm Millipore filter paper. Each piece of filter paper (of both types used) was then placed face-down on a semiselective medium for pythiaceous fungi (16). The plates were incubated in the dark for 2 days at 26 C. After incubation, the pieces of filter paper were removed and developing colonies were counted microscopically. Colonies were randomly sampled and placed on potato-dextrose agar (PDA) for identification after 2 days of incubation at 25 C in darkness.

Total bacterial, *Phytophthora*, and *Fusarium* colony counts were carried out on five 100-ml samples drawn from the remaining 10 1-L water samples. The samples were diluted serially to a final concentration of 10^{-2}. One-milliliter aliquots from the 10^{-2} dilution were plated onto PDA. The samples were spread over the surface of the medium with a sterile glass spreader and incubated in darkness at 27 C for 4 days. Protozoan and algal assessments were made by placing 10 ml from each 1-L sample onto PDA and recording the presence or absence of protozoans and algae after 4 days of incubation in continuous light at 25 C.

Chlorination and irrigation procedures. Chlorine gas was generated electrolytically by the Chlor 2000 (FCC Pty. Ltd., Johannesburg). This device generates chlorine gas from a brine solution that is then injected into the irrigation system by means of a positive displacement pump. Free available chlorine levels (uncombined chlorine radicals) in the water are regulated by altering the current supply. The level of free chlorine in the irrigation water was checked daily by a *N'N*-diethyl-*P*-phenylenediamine (DPD) test kit (10).

Irrigation was applied via drip irrigation with two emitters per tree, each delivering 2 L hr^{-1}. Irrigation was scheduled according to both evaporation pan and tensiometer readings (8) and fertilized according to local guidelines (9).

Water conditions at emitters. *Phytophthora* and nematodes (particularly *T. semipenetrans*) also were monitored at the emitters using two methods. The first method made use of the same broad sampling and analysis procedure as for the dam water, except that water samples were collected at the emitter. The second method was designed to monitor nematodes and *Phytophthora* only in the water being delivered to the plant. This was achieved by installing four modified leaf traps (H. F. Le Roux and M. E. C. Rea, *personal communication*) per treatment, each containing 10 citrus leaf pieces. The optimum time for running irrigation water through these traps was found to be 1 hr. At the end of the hour, the leaf pieces inside the traps were collected, placed in sterile distilled water, and plated onto a medium semiselective for *Phytophthora* (16). The plates were assessed for the presence of *Phytophthora* as above. The presence of colonies of *Fusarium* on these plates also was recorded. This procedure was repeated on 10 separate occasions. Nematodes were assessed by collecting the debris that accumulated in the bottom of the leaf trap and examining it microscopically for viable nematodes.

The level of free chlorine in the irrigation water also was checked at the emitters using the same procedure described above. The number of blocked emitters per 100 trees per treatment was assessed weekly to ascertain whether chlorination had any effect on the blockage. The minimum contact time of chlorine with water, from the time of injection into the irrigation system to water delivery at the tree, was assessed by the use of fluorescent dyes. These dyes were introduced into the main irrigation line and monitored at the three emitters closest to the point of injection. The minimum contact time was found to be 11 min. The pH of the water was maintained below 7 for the duration of the trial, thereby ensuring optimal biocidal activity. The pH of the water was adjusted by adding 1 M nitric acid to the irrigation water.

Fungal, bacterial, and nematode sensitivity to chlorination. *P. citrophthora*, *P. n. parasitica*, *Fusarium* sp., *Bacillus* sp., *Pseudomonas* spp., and the citrus nematode were tested for their sensitivity to free chlorine in the laboratory. Sodium hypochlorite was dissolved in autoclaved dam water to a level of 1, 2, 5, 10, 20, 30, 40, and 50 μg ml^{-1} free chlorine (11). Seven contact periods were investigated—0.5, 1, 2, 5, 10, 30, and 60 min. The pH was adjusted to 6.5 following the procedures described above.

Ten milliliters of each sodium hypochlorite dilution was placed in a test tube. Initially, 1 ml of a nematode suspension containing approximately 100 nematodes (of which approximately 30% were *T. semipenetrans*) was pipetted into each test tube. After exposure to the various chlorine levels, the bottom 1 ml was collected, placed in 100 ml of sterile distilled water, and filtered through a 38-μm filter. The remaining material was washed off and placed on a counting slide, and the live nematodes were counted. The free chlorine level was retested after each exposure period.

For tests on the fungi and bacteria, 1 ml of a suspension containing various levels of the test microbes was placed in the various chlorine solutions for the periods indicated. The naturally occurring microbial populations in these water samples were mainly found to be attached to organic debris. *Phytophthora* chlamydospores were found in the organic debris, whereas *Phytophthora* zoospores and bacterial cells occurred freely in the water. After exposure, the number of viable colonies was assessed by plating 1 ml of each suspension onto PDA for fungi or nutrient agar for bacteria and counting colonies 3 days after incubation at 25 C in the dark. The chlorine level was retested as it was for the nematode analysis.

Tree planting and trial layout. Delta Valencia citrus trees (a selection of *Citrus sinensis* (L.) Osbeck) grafted onto rough lemon (*Citrus jambhiri* Lush.) rootstock were produced in accordance with standard super-plant nursery procedures (17) and were regularly checked for the presence of *Phytophthora* and nematodes. During the first 2 wk of January 1988, the nursery trees were planted out on land that had not previously been cropped to citrus. The trees were planted

on ridges in soil that had been prepared in accordance with standard local recommendations (17).

Fifty trees each received chlorinated water with a free residual chlorine level of between 40 and 50 $\mu g\ ml^{-1}$ and unchlorinated water. The experiment was laid out using a randomized block design with single tree plots.

Soil and root analysis for *Phytophthora* and nematodes. A weekly soil and root analysis for *Phytophthora* and nematodes was undertaken on the trees receiving both the chlorinated and the untreated water. Ten individual tree samples per treatment, each consisting of 10 g of roots and 200 g of soil, were taken on five occasions. Each sample was later split for separate nematode and *Phytophthora* analysis, as described previously.

Glasshouse trials. In conjunction with these field experiments, glasshouse trials were conducted on 10-mo-old nursery trees (rough lemon rootstock budded with Delta Valencia). The trial was laid out using single-tree plots in a randomized design. Forty trees were used and checked for the presence of *Phytophthora* before experimentation. All of the tests were negative. All of the trees were irrigated with dam water (2 L every 2 days). Twenty trees received water chlorinated to a level of 10 $\mu g\ ml^{-1}$ after sand filtration. The other 20 trees received unchlorinated dam water. All of the trees were placed randomly as single-tree plots on raised benches with good drainage. In all cases, the pH of the irrigation water was maintained between 6 and 7 for the duration of the experiment as previously described.

Shoot growth measurements and *Phytophthora* analyses were made every 4 mo. The root infection level was measured by collecting 10 1-cm root pieces per replicate plant and plating them onto a medium selective for *Phytophthora* (16). The number of infected plants per treatment was recorded as a percentage of the total number of plants. After 1 yr, feeder root mass (dry weight) and shoot growth was recorded.

A similar procedure was followed on an additional group of *Phytophthora*-infected rough lemon and Troyer trees budded with Delta Valencia. Each rootstock group was divided into six groups of 10 trees and treated with chlorinated water containing free chlorine at 5, 10, 50, 100, 200, and 500 $\mu g\ ml^{-1}$. Each plant received 2 L of water every other day. The presence of *Phytophthora* in the rhizosphere of the treated plants was assessed weekly over a 10-wk period using the leaf-baiting technique (1). Propagule counts per gram of soil also were made for each plant 1 mo after the commencement of the trial, using the procedure described by Timmer et al (20). Three weeks after the start of the experiment, all of the plants were pruned back to 60 cm above soil level, and the new shoot growth was measured over a 3-mo period.

RESULTS

Field studies. The irrigation source (dam water) was found to contain parasitic nematodes including the citrus nematode. Similarly high levels of fungi pathogenic to citrus as well as bacteria, protozoans, and algae were found in the same water sources (Table 1).

The microbial analysis of the irrigation water arriving at the emitter proved to be similar to that of the dam water (Table 2), except overall microbial populations were lower.

The chlorine treatments eradicated the *Phytophthora*, *Fusarium*, algal, and protozoan populations present in the water.

Table 1. Microbial analysis of citrus irrigation source (dam water)

Sample batch	Nematodes[w]	*Phytophthora* sp.[x]	*Fusarium* sp.[y]	Bacterial sp.[y]	Algae[z]	Protozoans[z]
1	2,500	74	390	7,600	+	+
2	1,700	243	1,760	11,200	+	+
3	4,700	139	980	8,300	+	+
4	2,800	87	320	14,600	+	+
5	3,600	177	2,260	12,500	+	+

[w] Each value represents the total viable nematode counts in a given 100-L water sample, to the nearest 100, where the number of samples is 20.
[x] Each value represents the mean number of cfus of *Phytophthora nicotianae* var. *parasitica* and *P. citrophthora* per 1-L water sample, where the number of samples is 20.
[y] Each value represents the mean number of cfus of *Fusarium* sp. and bacteria per 1-L water sample, where the number of samples is 20 (rounded off to the nearest 10 for *Fusarium* and the nearest 100 for bacteria).
[z] Present in all 20 water samples.

Table 2. Microbial analysis of citrus irrigation water of drip emitters with and without chlorination

Batch no.[v]		Nematodes[w]	*Phytophthora*[x]	*Fusarium*[y]	Bacteria[y]	Algae[z]	Protozoans[z]
1	Control	130	37	740	1,500	+	+
	Chlorine	160	0	0	0	−	−
2	Control	40	127	390	2,600	+	+
	Chlorine	0	0	0	0	−	−
3	Control	0	43	470	900	+	+
	Chlorine	30	0	0	0	−	−
4	Control	120	92	980	1,400	+	+
	Chlorine	60	0	0	100	−	−
5	Control	270	261	660	300	+	+
	Chlorine	60	0	0	0	−	−

[v] Control is unchlorinated water. Chlorine is chlorinated water. Free chlorine level maintained at between 40 and 50 $\mu g\ ml^{-1}$.
[w] Each value represents the total viable nematode counts in a given 100-L water sample, to the nearest 100, where the number of samples is 20.
[x] Each value represents the mean number of cfus of *Phytophthora nicotianae* var. *parasitica* and *P. citrophthora* per 1-L water sample, where the number of samples is 20.
[y] Each value represents the mean number of cfus of *Fusarium* sp. and bacteria per 1-L water sample, where the number of samples is 20 (rounded off to the nearest 10 for *Fusarium* and the nearest 100 for bacteria).
[z] + = Present, − = absent.

Table 3. Continuous nematode and *Phytophthora* detection as monitored by the modified leaf trap method in chlorinated and unchlorinated water and the level of dripper plugging

Sample batch	*Phytophthora*[y]		Nematodes[y]		Dripper blocking[z]	
	Control	Chlorine	Control	Chlorine	Control	Chlorine
1	+	−	+	+	7	5
2	+	−	+	+	18	6
3	+	−	+	+	28	6
4	+	−	+	−	29	12
5	+	−	+	+	46	16
6	+	−	+	−	...	...
7	+	−	+	+	...	...
8	+	−	+	+	...	...
9	+	−	+	+	...	...
10	+	−	+	+	...	...

[y] + = Presence of *Phytophthora* or nematodes in the leaf trap collection apparatus, and − = their absence.
[z] Expressed as percentage. One hundred samples recorded on five occasions (weekly intervals, running sequentially).

Bacterial population levels in the water sources were dramatically reduced. The nematode levels in the irrigation water apparently were not affected by the chlorination treatment (Table 2). Similar treatment effects were observed in the continuous detection system employed at the drip emitter for *Phytophthora* and nematodes (Table 3). *Phytophthora* was once again shown to be completely eradicated, whereas a very slight reduction in nematode counts was observed. The level of blocked drippers in the chlorinated treatment was lower than in the unchlorinated treatment. Propagules of *Phytophthora* and nematodes in field soil and citrus roots were not affected by the chlorination of the irrigation water (Table 4).

In vitro, *T. semipenetrans* exhibited a high tolerance to free chlorine. A slight reduction in nematode viability was observed at high free-chlorine levels (40–50 $\mu g\ ml^{-1}$) and long contact periods (30–60 min). All of the nematodes included in the sample were similarly affected. All fungi and bacteria tested showed a high sensitivity to chlorine.

Glasshouse studies. In glasshouse container studies conducted over a period of 1 yr, the vigor, shoot, and feeder root growth of seedling citrus trees were reduced when irrigation water infested with *Phytophthora* (Table 5) was used. One control plant was found to have a low *Phytophthora* level in its rhizosphere, probably as a result of cross-contamination from infected plants.

Attempts to establish a dosage-response curve for chlorine on container-grown plants (Table 6) indicated that a trend existed in which increasing chlorine levels reduced the incidence of *Phytophthora* in the rhizosphere. These re-

Table 4. The effect[x] of chlorination of irrigation water on rhizospheric levels of the citrus nematode and *Phytophthora citrophthora* and *P. nicotianae* var. *parasitica* on citrus trees

Batch no.[y]	*P. n. parasitica*[z]		*P. citrophthora*[z]		Citrus nematode[z]	
	Root	Soil	Root	Soil	Root	Soil
1 Control	70	100	100	100	30	80
Chlorine	20	100	100	100	30	40
2 Control	40	100	50	70	0	30
Chlorine	80	60	100	20	10	40
3 Control	100	100	40	100	10	20
Chlorine	60	40	20	30	30	10
4 Control	20	100	100	60	20	70
Chlorine	50	70	80	40	0	0
5 Control	30	100	20	60	0	0
Chlorine	30	90	20	20	0	0

[x] Percentage of samples infected.
[y] Batches collected weekly, running concurrently.
[z] 10 replicates per treatment.

Table 5. The effect of water chlorination in water infested with *Phytophthora* on the growth of citrus grown in containers

Plant group	Foliar symptom expression[u]			Shoot extension[v] (cm)			*Phytophthora* root infection[w]			Dry root mass[x] (g)
	4 mo	8 mo	12 mo	4 mo	8 mo	12 mo	4 mo	8 mo	12 mo	12 mo
Unchlorinated	0 a[z]	15 a	35 a	14 a	27 a	33 a	80 a	80 a	60 a	9.7 a
Chlorinated[y]	0 a	0 b	0 b	22 a	31 a	56 b	0 b	0 b	10 b	16.8 b

[u] Mean percentage of plants exhibiting typical root rot canopy symptoms (i.e., chlorosis, wilting, defoliation) where the number of samples is 20.
[v] Mean main shoot extension as measured from the initiation of the experiment, where the number of samples is 20.
[w] Mean percent root infection as measured by taking 20 root pieces per plant and plating onto PARPH (16) to detect *Phytophthora*.
[x] Total mean dry feeder root mass in grams, where the number of samples is 20.
[y] The free chlorine level in the water was 10 $\mu g\ ml^{-1}$.
[z] Within columns, values followed by the same letter are not significantly different at $P = 0.05$ (Student-Newman-Keuls t tests).

Table 6. The effect of chlorinated water applications on shoot extension and *Phytophthora* incidence in the rhizosphere of Troyer (T) and rough lemon (R) rootstock

Rootstock	Chlorine[v]	*Phytophthora* incidence[w] (wk)								Mean propagule count[x]	Shoot extension[y] (cm)
		1	2	3	4	5	6	7	8		
R	0	90	90	100	30	100	100	100	100	162 a[z]	53 a
R	5	100	100	100	100	100	60	100	100	157 a	31 a
R	10	100	70	100	100	100	0	100	100	55 b	41 a
R	50	100	20	100	30	100	100	100	100	67 b	37 a
R	100	100	60	20	100	0	100	100	100	73 b	48 a
R	200*	60	100	0	60	10	60	60	0	26 c	32 a
R	500*	0	0	60	100	0	0	70	0	12 c	29 a
T	0	60	50	100	80	100	100	100	100	181 a	23 a
T	5	100	100	10	100	100	100	100	100	98 b	32 a
T	10	100	100	70	100	10	100	100	90	65 c	29 a
T	50	50	10	100	100	100	100	100	100	58 c	28 a
T	100	100	100	10	100	30	100	50	100	37 c	27 a
T	200*	60	100	0	0	90	70	0	80	7 d	19 a
T	500*	0	0	0	0	0	0	0	0	0 e	21 a

[v] Free available chlorine in $\mu g\ ml^{-1}$. * = Treatment levels that resulted in a consistently and significantly reduced *Phytophthora* incidence over the 8-wk period, using Fisher's protected multiple range test.
[w] *Phytophthora nicotianae* var. *parasitica* incidence assessed weekly for eight consecutive weeks, where the number of samples is 10.
[x] Mean propagule count per gram of soil, after 8 wk, where the number of samples is 10.
[y] Shoot extension after 12 wk, where the number of samples is 10.
[z] Values followed by the same letter do not differ from one another at $P = 0.01$ using the Student-Newman-Keuls test.

ductions became statistically significant only at chlorine levels of 200 μg ml^{-1} and higher. Multiple linear regression analyses indicated that both rootstocks behaved in a similar fashion in regard to their response to chlorine over the experimental period. At 500 μg ml^{-1}, chlorine eliminated *Phytophthora* from the growing medium of the Troyer rootstock without resulting in severe phytotoxicity symptoms. Chlorine had no statistically significant effect on the shoot growth of either rootstock cultivar, although shoot length tended to show a decrease with increases in the free chlorine levels applied.

DISCUSSION

One of the most serious of citrus diseases, Phytophthora root rot (14), is present in all the major production regions of the country (2) and is worsened by the fact that the local industry is based mainly on susceptible rootstocks. Most inland citrus water sources are infested with *Phytophthora* spp. pathogenic to citrus (H. F. Le Roux and N. M. Grech, *unpublished*). As such, irrigation water has constituted a major source of infection for citrus orchards.

Chlorination has been shown previously to be effective in controlling a wide range of citrus pathogens, including *Phytophthora* and *Fusarium* (15), as well as many others (4,6). In the past decade, microirrigation systems have become more common because of their higher efficiency (3). Microirrigation systems require that when water quality is poor, a substantial amount of the debris be removed to reduce emitter blocking (11). Indeed, this work has highlighted the additional advantage of the chlorine treatment in that the level of blocked drippers was lower because of a reduction in the amount of algal and bacterial slimes. These results are in accordance with previous work (5).

Although no apparent differences in tree growth were observed in the field during the experimental period (12 mo), the damaging effects of *Phytophthora* alone clearly were demonstrated in the glasshouse (Table 5), where an average reduction in dry root mass of 42% was observed in trees continually irrigated with water infested with *Phytophthora*. In glasshouse studies (Table 6), chlorine levels of 200–500 μg ml^{-1} were found to have a limited curative effect, in so far as these levels reduced the *Phytophthora* population levels on the rough lemon rootstock significantly and eradicated the fungus on the Troyer rootstock. A few Troyer trees did, however, show a slight defoliation at the 500 μg ml^{-1} level.

Typical canopy symptoms of *Phytophthora* infection were observed in several of the trees irrigated with infected water but not in those irrigated with chlorinated water. Shoot extension also was found to be reduced. Root infection was much higher in plants irrigated with infested water. Root infection decreased at the end of the 12-mo period. This can be related to the overall root condition, at which stage an extensive feeder root loss had occurred, and the remaining roots were rotted and colonized by opportunistic fungi.

Locally, as part of the South African Citrus Improvement Program, container-grown trees are produced in the nursery according to strict guidelines (17). Failure to adhere to these guidelines may result in nursery quarantine. Strict pathogen control can be achieved in the nursery by water treatment, fumigation of soil, and pesticide applications. Before planting out, soil is generally fumigated (particularly in replant situations), thereby reducing damaging soil pathogens (18). At present, however, field irrigation water generally is not treated for the elimination of plant pathogens.

The control of citrus feeder root and collar rot is extremely costly and not always successful (20). Treatment of the problem is usually too late when substantial root damage has occurred. It is becoming more widely acknowledged that preventive treatments are far more efficient and cost effective. Chlorinated irrigation water will prevent the introduction of damaging root pathogens such as *Phytophthora*. Because of the relatively low cost of electrolytically generated chlorine, it is now possible to include chlorinated irrigation water, along with conventional fungicides, soil fumigation, and other cultural practices, in orchard management programs.

In the nursery, chlorine may be useful as a curative agent, especially when combined with certain registered fungicides. Indeed, chlorine's efficacy as an eradicant of *Phytophthora* may be improved in containerized citrus if sandier potting mixtures are used. This is because of chlorine's inherent affinity for binding to organic matter. It follows, then, that the lower organic matter content of sandy mixtures will probably result in greater levels of free chlorine and, hence, in a higher biocidal activity.

These studies have shown that electrolytically generated chlorine can be used cost effectively in citrus microirrigation systems for the elimination of certain pathogens in the water, including *Phytophthora*, at a fraction of the cost of other forms of chlorine. An additional advantage of the unit is that sodium hydroxide is produced as a by-product. This product has a current selling price equivalent to $300/t. Present unit cost (locally) per kilogram of chlorine (100% free available) produced is $1.60 for liquefied chlorine gas, $2.70 for sodium hypochlorite (15%, w/v) solution, $2.87 for dry calcium hypochlorite (70%, w/v), $3.64 for TCIA tablets, and 34¢ for electrolytically generated chlorine. With careful management, chlorination of irrigation water for citrus orchards is recommended where water sources are infested with damaging microorganisms such as *Phytophthora*. The possibility of using similar chlorination systems on other crop systems is being investigated.

ACKNOWLEDGMENTS

We thank P. Fletcher and S. van Vuuren (FCC Pty. Ltd.) for their assistance. We also thank T. Pienaar of Riverside Citrus Estates for his cooperation and for the use of various citrus orchards. We thank R. T. Frean for his assistance in the preparation of the manuscript and Jean Piaget for his useful criticisms of the manuscript.

LITERATURE CITED

1. Anderson, E. J. 1950. A simple method for detecting the presence of *Phytophthora cinnamomi* Rands in soil. Phytopathology 41:187-189.
2. Anonymous. 1988. Pages 1-4 in: Citrus decline. Citrus and Subtropical Fruit Research Institute, South African Citrus Exchange and Ciba-Geigy, Ciba-Geigy Pty. Ltd., South Africa.
3. Bredell, G. S., and Barnard, C. J. 1977. Microjets for macro efficiency. Proc. Int. Soc. Citric. 1:87-92.
4. Brown, E. G., and Wardowski, W. F. 1986. Use of chlorine and chlorine dioxide in Florida citrus packinghouses. Citrus Ind. 67(6):45.
5. Bui, H. 1982. Guidelines for chlorination of drip irrigation systems. Pages 14-21 in: Hawaii. Sugar Plant. Assoc. Irrig. Rep. 79.
6. Datnoff, L. E., Kroll, T. K., and Lacy, G. H. 1987. Efficacy of chlorine for decontaminating water infested with resting spores of *Plasmodiophora brassicae*. Plant Dis. 71:734-736.
7. D'Onofrio, A. B. 1988. Your water treatment options. Citrus Ind. 69(1):9-62.
8. Du Plessis, S. F. 1988. Citrus irrigation management. Farming S. Afr.
9. Du Plessis, S. F. 1988. Fertilization of Citrus. Farming S. Afr.
10. Ford, H. W. 1980. Using a D.P.D. (*N'N*-diethyl-*P*-phenylenediamine) test kit for measuring free available chlorine. Pages 24-29 in: Univ. Fla. Inst. Food Agric. Sci. Res. Rep. CS79-1.
11. Ford, H. W., and Tucker, D. P. H. 1974. Water quality measurements for drip irrigation systems. Proc. Fla. State Hortic. Soc. 87:58-60.
12. Grandsbury, J. 1984. Water treatment is a vital part of micro-irrigation systems. Aust. Grapegrower Winemaker. April:52-59.
13. Grech, N. M., and Frean, R. T. 1987. Water purification systems for nurseries. Subtropica 8:10-12.
14. Grech, N. M., Frean, R. T., and Williams, S. G. 1989. The use of ultraviolet radiation combined with filtration for the decontamination of irrigation water in citrus and sub-tropical fruit nurseries. Phytophylactica 21:247-249.
15. Hough, A. 1979. Treatment of irrigation water for the removal of fungi and nematodes. S. Afr. Coop. Citrus Exch. Rep. pp. 12-14.
16. Jeffers, S. N., and Martin, S. B. 1986. Comparison of two media selective for *Phytophthora* and *Pythium* species. Plant Dis. 70:1038-1043.
17. Lee, A. T. C. 1988. Guidelines for the production of container grown citrus trees in Southern Africa. S. Afr. Citrus Exch. Rep. 68 pp.
18. Le Roux, H. F. 1985. Effect of soil solarization and chemical treatments on root disorders of citrus. M. S. thesis. University of Pretoria, Pretoria, South Africa.
19. Piaget, J. 1988. Chlorinate for a free flow. Farmers Weekly. September 9 1988 pp. 24-27.
20. Timmer, L. N., Graham, J. E., Sandler, H. A., and Zitko, S. E. 1988. Populations of *Phytophthora parasitica* in bearing citrus orchards in Florida and tree response to fungicide applications. Citrus Ind. 69(11):40-44, 54.
21. White, G. C. 1972. Handbook on Chlorination. Van Nostrand Reinhold Co., New York. 744 pp.