Efficacy of Nonionic Surfactants in the Control of Zoospore Spread of *Pythium aphanidermatum* in a Recirculating Hydroponic System

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ABSTRACT

Stanghellini, M. E., Rasmussen, S. L., Kim, D. H., and Rorabaugh, P. A. 1996. Efficacy of nonionic surfactants in the control of zoospore spread of *Pythium aphanidermatum* in a recirculating hydroponic system. Plant Dis. 80:422-428.

Zoosporic fungi are among the most destructive root pathogens in recirculating hydroponic cultural systems, and zoospores have been implicated as the primary, if not sole, infectious propagule responsible for the spread of these pathogens via the recirculating nutrient solution. In vivo experiments employing cucumbers as the susceptible host and *Pythium aphanidermatum* as the root pathogen demonstrated the efficacy of surfactants in the control of root disease caused by this fungus. Amending the recirculating nutrient solution with a nonionic surfactant (final concentration, 20 μg a.i./ml) resulted in complete control of the spread of the fungus via the recirculating nutrient solution. Zoospores were identified as the sole propagule responsible for pathogen dissemination in the recirculating nutrient solution. In the absence of a surfactant, all plants within a recirculating hydroponic unit were killed within 5 to 6 weeks following hypocotyl inoculation of a single plant in the hydroponic unit.

Additional keywords: lettuce, peppers, *Phytophthora capsici, Plasmopara lactucae-radicis*

Zoosporic fungi, particularly those belonging to the genera *Pythium* and *Phytophthora*, have been documented as the most common and destructive root-infecting pathogens of vegetable crops in recirculating hydroponic cultural systems (3). Once these pathogens are introduced into such a cultural system, their control is often difficult and commonly requires the shutdown and disinfestation of the entire system. Although certain fungicides (propamocarb and metalaxyl) capable of providing a high degree of disease control are available, they are not registered for use on vegetable crops cultivated in hydroponic systems in the United States.

In the early 1980s, Tomlinson et al. reported on the efficacy of surfactants in the control of lettuce big vein disease (5), which is caused by a virus vectored by *Olpidium brassicae* (Woronin) P.A. Dang., and melon necrotic spot of cucumbers (6), which is caused by a virus vectored by *Olpidium radicale* Schwartz & Ivimey Cook. Zoospores of these two species of *Olpidium* were demonstrated to rapidly lyse when exposed to a surfactant. The lytic action of surfactants is not restricted, however, to zoospores of *Olpidium*. Studies conducted in 1987 (4) demonstrated the lytic action of surfactants to zoospores, as well as vesicles, of *Pythium aphanidermatum* (Edson) Fitzp., *P. dissotocum* Drechs., *P. intermedium* de Bary, *P. tracheiphilum* Matta, and *Phytophthora nicotianae* Breda de Haan.

Our objectives were to assess, under near-commercial conditions, the method(s) of pathogen spread in a recirculating hydroponic system and the efficacy of surfactants in the control of root disease of hydroponically grown cucumber caused by *P. aphanidermatum*. A preliminary report has been published (2).

This research was funded in part by grant number IS-2115-92 from BARD.

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Accepted for publication 1 February 1996.

Publication no. D-1996-0220-04R
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MATERIALS AND METHODS

Host and pathogen. The host crop employed in the following experiments included two cultivars of cucumber (*Cucumis sativus* L. cvs. Corona and Toska). Seeds of the respective cultivars were sown in Grodan Rockwool cubes (2.5 × 5 cm) and fertilized daily for 2 weeks in a greenhouse (24 to 34°C). A virulent isolate of *P. aphanidermatum*, originally obtained from hydroponically grown cucumbers, was used in all studies. Stock cultures of the fungus were stored in sterile distilled water, and working cultures were reared on V8 agar medium.

Hydroponic cultural system. All experiments were conducted in a temperature-controlled (24 to 34°C) greenhouse where 12 separate recirculating hydroponic units were constructed (Fig. 1). Each hydroponic unit (Fig. 2) consisted of two rock wool slabs (each 100 × 7.5 × 20 cm) connected to a common reservoir containing 50 liters of a nutrient solution. Slabs, located on a bench ca. 40 cm above ground level, were contained in plastic trays and wrapped in black-on-white plastic sheeting, white side out. The nutrient

Fig. 1. Photograph of 12 separate hydroponic units in a temperature-controlled greenhouse.

solution was then pumped from the reservoir to the bench top and distributed to each plant via drip tubing outfitted with a 3.8 liter/h emitter. Excess nutrient solution from each slab drained by gravity back to the reservoir and was recirculated. Plants were irrigated at 30-min intervals 5 to 12 times between 6 A.M. and 6 P.M., and 5 to 9 times between 6 P.M. and 6 A.M. (depending on time of year and stage of plant growth). The nutrient solution was maintained between pH 5.7 and 6.0 using Omega PHCN-36 pH controllers and Orion 91-56 combination pH electrodes. The nutrient solution composition and elemental concentrations, in µg/ml, were as follows: Mg 48.8, S 64.5, P 62.1, K 241.5, N 222.7, Ca 235.1, B 0.44, Cu 0.05, Cl 0.85, Mn 0.62, Mo 0.06, Zn 0.09, and Fe 2.5. The electrical conductivity (EC 2.5 mS/cm^2) and the nutrient solution volume in reservoirs were monitored daily, and levels were maintained as required.

Four 2-week-old cucumber seedlings in rock wool cubes were transplanted onto each rock wool slab (eight plants per hydroponic unit). The distance between plants on individual slabs was 20 cm. The plants were then trained to a wire 1.8 m above the slab using the umbrella system, and two laterals were allowed to grow down from the top. In some treatments, shoot tip growth of each plant was measured daily until the plants reached the top wire. Marketable fruit (commercial grades of Extra and Class 1 and 2) were harvested three times per week beginning ca. 45 days after seeding, and the number of fruit from each plant were recorded.

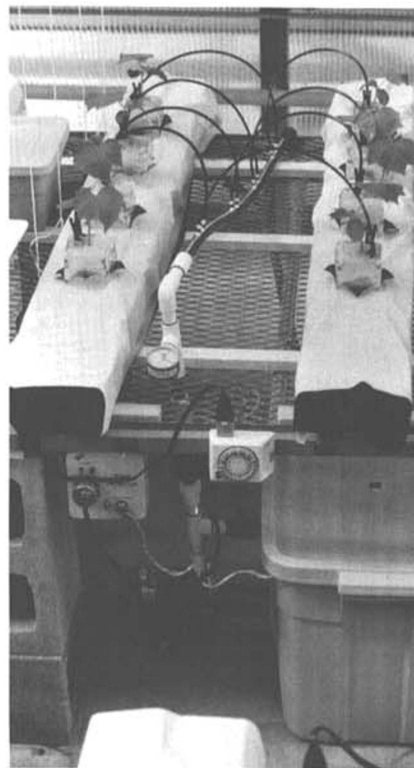

Fig. 2. Photograph of an individual recirculating hydroponic unit. Two rock wool slabs, each containing four cucumber plants, were connected to a reservoir containing 50 liters of nutrient solution.

There were five cropping periods (conducted over a 2-year period), and each cropping period, unless otherwise indicated, was 84 days in duration. After completion of a cropping period, the entire hydroponic system in the greenhouse was dismantled, surface sterilized in sodium hypochlorite (10%), and reassembled.

There were 11 different treatments. The number of treatments and treatment replications (herein called trials) per cropping period are summarized in Table 1. Not all treatments were repeated or replicated in each cropping period.

Methods of unit infestation. Two methods of pathogen infestation of an individual hydroponic unit were employed. First, a 5-mm-diameter disk, cut from the advancing margin of a 5-day-old V8 agar culture of the pathogen, was placed in contact with the lower hypocotyl (immediately below the substrate surface) of one plant on one side (side A) of a hydroponic unit (Fig. 3). The agar disk was removed after 24 h. The hypocotyl-inoculation method was the primary method of infestation employed, since it permitted us to evaluate the method of pathogen spread in a recirculating hydroponic system subsequent to natural colonization of a single plant. Second, a suspension of zoospores was added to the reservoir (Fig. 3). Final concentration in the reservoir, depending upon the particular trial, ranged from 0.2 to 2 zoospores (or encysted zoospores) per ml. Zoospores were produced in the laboratory and enumerated as previously described (4). For studies requiring encysted zoospores, a portion of the motile population was vigorously agitated for ca. 2 min. Microscopic examination subsequent to agitation showed that all zoospores had encysted. Infestation of individual units occurred at two time periods. Units were infested either 1 week after transplant (day 21) or 6 weeks after transplant (day 56). Variation in time of infestation was conducted to evaluate the influence of plant age on the relative susceptibility of the host crop. Noninfested units served as controls.

Surfactants. Two nonionic surfactants (Agral 90, ICI, and AquaGro 2000L, Aquatrols, Cherry Hill, NJ) were used. The final reservoir concentration was 20 µg a.i./ml. Preliminary in vivo studies showed that higher surfactant concentrations were phytotoxic. Preliminary in vitro studies also confirmed previous studies (4) regarding the lytic effect of these two surfactants to motile zoospores but not to hyphae or encysted zoospores. Surfactants were added to the reservoirs 24 h prior to transplant. Visual foaming in the reservoir was regarded as evidence of the presence of the surfactant. Upon the disappearance of foaming, surfactants were reapplied. The frequency of surfactant reapplication varied from 14 to 21 days.

Monitoring root infection and zoospore populations. Sections of rock wool measuring ca. 2 cm^2 were excised from the rock wool slab at weekly intervals over the cropping period. Five to 10 root segments, ca. 2 cm in length, were extracted from each rock wool section, washed in running tap water for 5 min, blotted dry, and plated on water agar medium. After 24 h incubation at 27°C, hyphae emerging from the roots were transferred to V8 agar medium, and the cultures were identified. Additionally, the surface of roots extracted from the rock wool slabs were microscopically observed for the presence of hyphae and sporangia.

Zoospore populations in the recirculating nutrient solution were detected in certain treatments as follows: four 10-ml samples of nutrient solution were collected weekly from one emitter on each side of certain treatments and transported to the laboratory. The samples were vigorously agitated for 2 min to induce encystment of any motile zoospores. Samples were then

Table 1. Summary of the number of treatments and replications in each of five cropping periods. Each cropping period ranged from 84 to 98 days in duration

Treatments	Cropping period				
	1	2	3	4	5
Control	2[a]	2	2	2	3
Control + surfactant	–	2	2	2	–
Seedling plants (21 days old)					
Reservoir infestation with motile zoospores	2	–	–	1	1
Hypocotyl inoculation	4	2	2	2	2
Hypocotyl inoculation + surfactant	–	2	4	2	2
Hypocotyl inoculation + surfactant, discon.	–	–	1	2	1
Adult plants (56 days old)					
Reservoir infestation with					
Motile zoospores	2	1	–	1	1
Encysted zoospores	–	–	–	–	1
Encysted zoospores + surfactant	–	–	–	–	1
Hypocotyl inoculation	2	1	–	–	–
Hypocotyl inoculation + surfactant	–	2	1	–	–

[a] The number of treatment replications (trials) per cropping period.

passed through a Millipore filter (3-µm pore diameter). The filter was imprinted, top side down, on the surface of a species-specific selective agar medium (1) contained in petri dishes. The filter was removed, and the dishes were incubated at 37°C. After 48 h incubation, developing colonies on the agar were enumerated, and subcultures were taken for species identification. The size and nature of the propagule giving rise to each colony was microscopically determined. Preliminary studies showed that ca. 92% of a known number of encysted zoospores collected on the filter produced colonies on the selective medium.

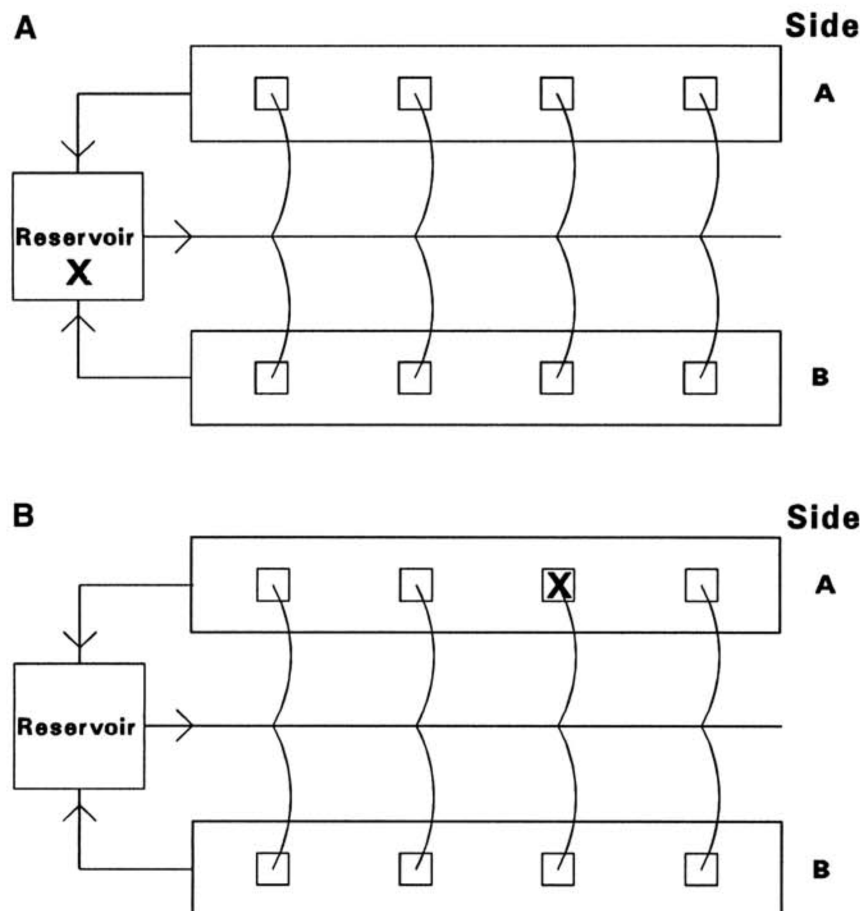

Fig. 3. Schematic of a recirculating hydroponic unit employed to evaluate the efficacy of surfactants in the control of root rot of cucumber caused by *Pythium aphanidermatum*. Two methods of inoculation with the pathogen were used: **(A)** infestation of the reservoir (X) with motile or encysted zoospores or **(B)** hypocotyl-inoculation of a single plant (X) on one side (side A) of a hydroponic unit.

Data analysis. All data, when appropriate, were subjected to analysis of variance (ANOVA). Lack of significant variation, as shown by Bartlett's test of homogeneity, permitted the combining of data regarding the efficacy of the two surfactants or the susceptibility of the two cultivars of cucumbers employed. Mortality data are presented per side A or B of a hydroponic unit.

RESULTS

Hypocotyl-inoculation in the absence of a surfactant. Within 4 to 6 weeks after inoculation of the hypocotyl of a single plant on side A within a hydroponic unit, all eight plants, irrespective of plant age at time of inoculation, were killed (Tables 2 and 3, Figs. 4A and 5A). Plants on the inoculated side initially had a faster mortality rate than plants on the noninoculated side. The mortality rate of plants in units inoculated at 56 days of age was faster than the rate in units inoculated at 21 days of age. Compared to the noninoculated control units, significant cumulative yield reductions occurred in all inoculated units.

Zoospores (1 to 4 per ml) were first detected in nutrient solution samples collected ca. 13 days after hypocotyl-inoculation of a single plant on side A of a unit. Microscopic examination showed that all colonies originated from propagules ca. 10 µm in diameter. Additionally, extensive hyphal growth and sporulation by the pathogen was microscopically observed on necrotic roots extracted from the rock wool slabs supporting dead as well as infected plants. *P. aphanidermatum* was

Table 2. Percent mortality of seedling cucumber plants after hypocotyl-inoculation of a single plant on one side (side A) of a recirculating hydroponic unit with *Pythium aphanidermatum*

		Days[a]															
Treatment	**Side**	**S 0**	**7**	**T 14**	**I 21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**	**Yield[b]**
Control[c]	A	0	0	0	0	0	0	0	0	0	0	0	0	0			37
	B	0	0	0	0	0	0	0	0	0	0	0	0	0			48
Surfactant[d]	A	0	0	0	0	0	0	0	0	0	0	0	0	0			34
	B	0	0	0	0	0	0	0	0	0	0	0	0	0			36
Pythium[e]	A	0	0	0	0	10	30	88	100								0*
	B	0	0	0	0	0	0	11	48	63	100						0.4*
Pythium + surfactant[f]	A	0	0	0	0	10	35	72	95	100							1*
	B	0	0	0	0	0	0	0	0	0	0	0	0	0			43
Pythium + surfactant[g]	A	0	0	0	0	13	54	83	96	100							0*
						Surfactant discontinued ↘											
	B	0	0	0	0	0	0	0	0	0	0	0	4	58	75	100	48

[a] Cucumbers seeded (S) on day 0, transplanted (T) on day 14, and inoculated (I) on day 21.
[b] Yields (number of marketable fruit) marked with an * are significantly different from unmarked yields, according to ANOVA, $P < 0.01$.
[c] Mean percent mortality in 11 trials. There are four plants on side A and four plants on side B.
[d] Mean percent mortality in six trials.
[e] Mean percent mortality in 12 trials.
[f] Mean percent mortality in 10 trials.
[g] Mean percent mortality in four trials.

consistently isolated from the roots of all infected and dead plants.

No plant mortality occurred in noninoculated control units, and the fungus was not isolated from or observed on roots sampled periodically throughout the cropping period (84 days) (Tables 2 and 3).

Hypocotyl-inoculation in the presence of a surfactant. In surfactant-amended units, all of the plants on the inoculated side (side A) of a unit, irrespective of plant age at time of inoculation, were killed within 5 weeks; but none of the plants on side B of a unit were either infected or killed over the entire 84-day cropping period (Tables 2 and 3, Figs. 4B and 5B). No zoospores or other colony-forming units of the pathogen were detected in samples of the nutrient solution collected from emitters on side A or B throughout the cropping period. The fungus was, however, consistently isolated from roots sampled throughout the cropping period from the inoculated side (side A) of a unit, and extensive hyphal growth and sporulation by the pathogen were microscopically observed on roots of infected and dead plants that were extracted from the rock wool slabs on the inoculated side (side A) of the unit. Significant reductions in marketable yield occurred on the inoculated side (side A) of the unit; whereas no yield reductions, in comparison to yields from control units, occurred on side B of a surfactant-amended unit.

In four trials, 100% mortality of the plants on side B of a surfactant-amended unit occurred ca. 7 weeks after surfactant treatments were discontinued (Table 2).

Table 3. Percent mortality of adult cucumber plants after hypocotyl-inoculation of a single plant on one side (side A) of a recirculating hydroponic unit with *Pythium aphanidermatum*

		Days[a]													
Treatment	**Side**	**S 0**	**7**	**T 14**	**21**	**28**	**35**	**42**	**49**	**I 56**	**63**	**70**	**77**	**84**	**Yield[b]**
Control[c]	A	0	0	0	0	0	0	0	0	0	0	0	0	0	36
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Pythium[d]	A	0	0	0	0	0	0	0	0	0	25	50	58.3	100	19*
	B	0	0	0	0	0	0	0	0	0	0	33.3	58.3	100	29*
Pythium +[d]	A	0	0	0	0	0	0	0	0	0	8	33.3	58.3	100	25*
surfactant	B	0	0	0	0	0	0	0	0	0	0	0	0	0	40

[a] Cucumbers seeded (S) on day 0, transplanted (T) on day 14, and inoculated (I) on day 56.
[b] Yields (number of marketable fruit) marked with an * are significantly different from unmarked yields, according to ANOVA, $P = 0.05$.
[c] Mean percent mortality in six trials. There were eight plants per trial: four plants on side A and four plants on side B.
[d] Mean percent mortality in three trials.

Fig. 4. Mortality of seedling cucumber plants after hypocotyl-inoculation of a single plant (X) on one side of a two-sided recirculating hydroponic unit in the absence (**A**) or presence (**B**) of a nonionic surfactant.

Fig. 5. Mortality of adult cucumber plants after hypocotyl-inoculation of a single plant on one side of a two-sided recirculating hydroponic unit in the absence (**A**) or presence (**B**) of a nonionic surfactant.

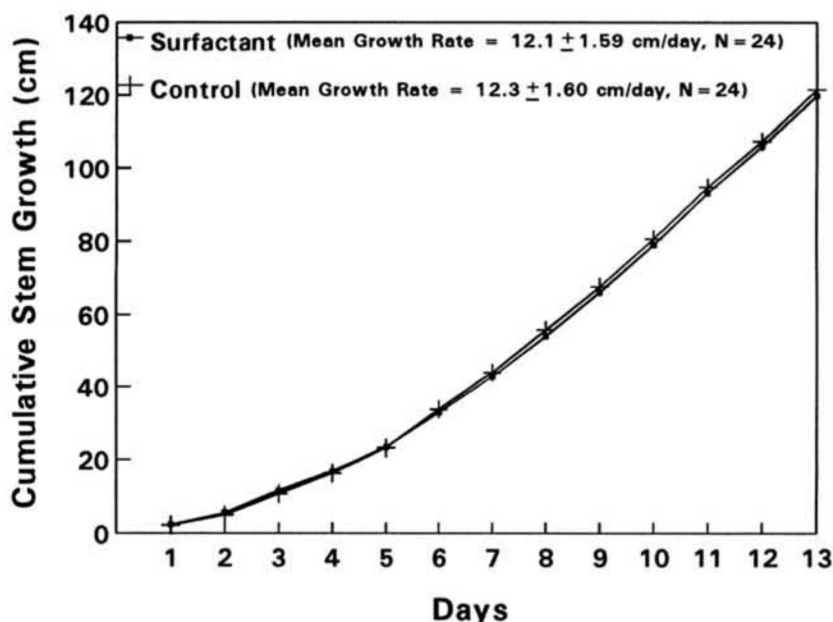

Fig. 6. Shoot tip growth rates of cucumber plants in the presence or absence of a nonionic surfactant.

The duration of the cropping periods in the above trials were extended until all plants within the hydroponic unit died (i.e., 98 days).

No plant mortality occurred in any of the noninoculated control units, and the fungus was not isolated from roots of control plants that were periodically collected throughout the 84-day cropping period. Additionally, no significant differences were detected, in three trials, in either shoot tip growth rates (which ranged from ca. 11 to 13 cm/day during the exponential growth phase) or marketable yields of plants grown in surfactant-amended compared to nonamended nutrient solutions (Fig. 6, Table 2).

Reservoir infestation with motile zoospores. *Seedling plants.* Four trials were conducted in which motile zoospores (final concentration of 2 zoospores per ml) were added to the reservoirs servicing 21-day-old seedling plants. Infection and mortality occurred in only one of the trials, and all of the seedlings in the latter trial were killed within 4 weeks following infestation of the reservoir. No root infection or plant mortality occurred in the other three trials over the duration (84 days) of the cropping period (Table 4).

Adult plants. In each of five trials, all of the adult, fruit-bearing plants were killed within 2 to 3 weeks following infestation of the reservoir (on day 56) with pathogen populations ranging from 0.2 to 2 zoospores per ml (Table 5). *P. aphanidermatum* was consistently isolated from the roots of all dead plants. No root infection or mortality of plants occurred in the respective noninoculated control hydroponics units.

Reservoir infestation with encysted zoospores in the absence or presence of a surfactant. In the absence or presence of

Table 4. Percent mortality of seedling cucumber plants after infestation of the reservoir of a recirculating hydroponic unit with motile zoospores of *Pythium aphanidermatum*

		Days[a]												
Reservoir infestation[b]	**Side**	**S 0**	**7**	**T 14**	**I 21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**
Control[c]	A	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0
Trial 1[d]	A	0	0	0	0	0	25	50	100					
	B	0	0	0	0	25	50	75	100					
Trials 2,3,4[d]	A	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0

[a] Cucumbers seeded (S) on day 0, transplanted (T) on day 14, and infested (I) on day 21.
[b] Motile zoospores (final concentration = 2.0 zoospores per ml) were added to the nutrient solution in the reservoir on day 21.
[c] Mean percent mortality in seven trials. There were eight plants per trial: four plants on side A and four plants on side B.
[d] Mean percent mortality in four trials. Mortality occurred in only one of the four trials.

Table 5. Percent mortality of adult cucumber plants after infestation of the reservoir of a recirculating hydroponic unit with motile zoospores of *Pythium aphanidermatum*

		Days[a]												
Reservoir infestation[b]	**Side**	**S 0**	**7**	**T 14**	**21**	**28**	**35**	**42**	**49**	**I 56**	**63**	**70**	**77**	**84**
Control[c]	A	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0
2 zoospores/ml[d]	A	0	0	0	0	0	0	0	0	0	37	100		
	B	0	0	0	0	0	0	0	0	0	37	88	100	
1 zoospore/ml[e]	A	0	0	0	0	0	0	0	0	0	0	100		
	B	0	0	0	0	0	0	0	0	0	0	100		
0.2 zoospore/ml[e]	A	0	0	0	0	0	0	0	0	0	0	100		
	B	0	0	0	0	0	0	0	0	0	25	100		

[a] Cucumbers seeded (S) on day 0, transplanted (T) on day 14, and infested (I) on day 56.
[b] Motile zoospores, at populations indicated, were added to the nutrient solution in the reservoir on day 56.
[c] Mean percent mortality in nine trials. There were eight plants per trial: four plants on side A and four plants on side B.
[d] Mean percent mortality in three trials.
[e] Percent mortality in one trial.

Table 6. Percent mortality of adult cucumber plants after infestation of the reservoir of a recirculating hydroponic unit with encysted zoospores of *Pythium aphanidermatum*

		Days[a]									
Reservoir infestation[b]	**Side**	**S 0**	**7**	**T 14**	**21**	**28**	**35**	**42**	**I 49**	**56**	**63**
Control[c]	A	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0
Encysted[d]	A	0	0	0	0	0	0	0	0	0	100
	B	0	0	0	0	0	0	0	0	0	100
Encysted+[d]	A	0	0	0	0	0	0	0	0	50	100
surfactant	B	0	0	0	0	0	0	0	0	0	100

[a] Cucumbers seeded (S) on day 0, transplanted (T) on day 14, and infested (I) on day 49.
[b] Encysted zoospores (final concentration = 2.0 zoospores per ml) were added to the nutrient solution in the reservoir on day 49.
[c] Mean percent mortality in three trials.
[d] Percent mortality in one trial.

a surfactant, all adult plants were killed within 2 weeks after infesting the reservoir with 2 encysted zoospores per ml (Table 6).

DISCUSSION

In commercial recirculating hydroponic facilities, hundreds to thousands of individual rock wool slabs, each containing two to four plants, are employed. Epidemics caused by zoosporic root-infecting fungi usually develop following colonization of only a few plants. These infected plants serve as a source of secondary inocula for infestation of the entire system.

The results of our investigations, which were designed to evaluate pathogen spread from a point source (i.e., hypocotyl-inoculation of a single plant within a recirculating hydroponic system), (i) demonstrated that there are two methods of pathogen spread within a recirculating rock wool hydroponic system, and (ii) documented for the first time the efficacy of surfactants in the control of the spread, via recirculation of pathogen-infested nutrient solution, of one of the more destructive root-infecting pathogens, *P. aphanidermatum,* in such a cultural system. First, the fungus can spread from plant to plant via hyphae. The highly compartmentalized nature of a rock wool cultural system, however, limits hyphal spread from a point source to plants growing within an individual rock wool slab. Second, the fungus can spread via zoospores in the recirculating nutrient solution. The latter method of spread is the sole method of dissemination of the pathogen via the recirculating nutrient solution. Evidence for these conclusions is derived from our studies involving the presence or absence of surfactants in the recirculating nutrient solution.

Surfactants previously (4) were shown to rapidly kill (via lysis of the plasma

membrane) fungal structures lacking a cell wall, i.e., zoospores and/or vesicles; but they had no effect on fungus structures possessing a cell wall (i.e., hyphae, encysted zoospores, or sporangia). Our current studies provide in vivo evidence that supports the latter observations. In the absence of a surfactant, zoospores, which were produced naturally on a single hypocotyl-inoculated plant, spread via the recirculating nutrient solution. Within 6 weeks following inoculation of a single plant, all plants within a hydroponic unit (irrespective of plant age at the time of inoculation) were killed. However, amending the nutrient solution with a nonionic surfactant limited pathogen spread, via hyphae, to plants growing within the same individual rock wool slab but eliminated spread of the pathogen, via zoospores, in the recirculating nutrient solution. Since no root infection or mortality occurred on the noninoculated side of a surfactant-amended hydroponic unit, we conclude that motile zoospores were the sole propagule responsible for natural spread of the pathogen via the recirculating nutrient solution. Microscopic examination revealed that all colony-forming units in the recirculating nutrient solution, in the absence of a surfactant, originated from propagules the size of zoospores. No zoospores or other colony-forming propagules were detected in surfactant-amended nutrient solution. If any encysted zoospores were present in the recirculating nutrient solution, all of the plants within a surfactant-amended system would have been killed, since surfactants, as demonstrated in our study, are not lytic to these fungal structures. Additionally, our results indicate that hyphal fragments, which hypothetically could be dislodged from infected roots, either do not occur or do not function as effective inoculum for dissemination in the recirculating nutrient solution. No mortality or root infection occurred on the noninoculated side of a surfactant-amended unit despite the fact that extensive hyphal growth by the pathogen was consistently observed on the roots of infected and dead plants on the inoculated side (side A) of a recirculating unit throughout the entire cropping period.

The successful employment of surfactants for the control of zoosporic pathogens, such as *P. aphanidermatum*, in recirculating hydroponics is predicated upon the premise that most epidemics develop from a few scattered disease foci within a production facility and that spread within a hydroponic system is due to the dissemination of secondary inoculum, i.e., zoospores, via the recirculating nutrient solution. Effective disease control with surfactants will not be achieved, however, if encysted zoospores are introduced into the production facility in quantities sufficient to colonize at least one plant in each rock wool slab. Once host colonization occurs, the fungus can spread from plant to plant within a rock wool slab via hyphae. The introduction of zoospores (most likely in the encysted state) into a production facility in such high numbers could occur if infested surface waters from lakes, rivers, streams, holding ponds, etc., are employed as a source of water. Although infested surface waters can serve as a source of pathogen introduction into a commercial facility (3), it has been our experience, over some 25 years, that simultaneous infestation of numerous plants within a commercial facility via this method of pathogen introduction seldom occurs. For obvious reasons, the use of surface water is not recommended, since pathogen colonization of even a single plant constitutes a serious threat to the entire plant population in a recirculating hydroponic system.

The results of our studies involving infestation of the reservoir with known populations of motile or encysted zoospores demonstrated their efficiency as inoculum. However, their success in colonizing the host is apparently related to plant age. For example, infestation of reservoirs servicing adult plants (56 days in age) with populations ranging from 0.2 to 2 zoospores per ml consistently (five out of five trials) resulted in 100% mortality. Yet when reservoirs servicing seedling plants (21 days of age) were artificially infested with zoospores (only populations of 2 zoospores per ml were used), successful host colonization and subsequent mortality occurred in only one of four trials. In our opinion, successful colonization was not due to an inherent increase in plant susceptibility with age but rather due to chance encounter between a zoospore and a plant root. Adult plants have more roots than young plants, and the probability of encounter increases as plant age increases. The low probability of host colonization of seedings following artificial infestation of the reservoir with zoospores also indicates that zoospores function as effective inoculum for only relative short periods of time. No root infection or plant mortality occurred in three of the units that were infested with 2 zoospores per ml despite the fact that the plants in these infested units were grown for 63 days beyond the date of infestation.

In addition to the previously published attributes of surfactants (4), our results also indicate that surfactants, at the rates used in our study, have no deleterious effects on plant growth or yield. Studies of the efficacy of surfactants in the control of zoosporic fungi other than *P. aphanidermatum* are in progress. These studies include *Phytophthora capsici* and *Plasmopara lactucae-radicis* on peppers and lettuce, respectively. The results of the latter studies, which are being conducted under hydroponic conditions as well as in naturally infested commercial fields, will be presented separately.

LITERATURE CITED

1. Burr, T. J., and Stanghellini, M. E. 1973. Propagule nature and density of *Pythium aphanidermatum* in field soil. Phytopathology 63:1490-1501.
2. Rasmussen, S. L., Stanghellini, M. E., Kim, D. H., and Rorabaugh, P. 1995. Efficacy of surfactants in the control of zoosporic root-infecting fungi. (Abstr.) Phytopathology 85:1167.
3. Stanghellini, M. E., and Rasmussen, S. L. 1994. Hydroponics: A solution for zoosporic pathogens. Plant Dis. 78:1129-1138.
4. Stanghellini, M. E., and Tomlinson, J. A. 1987. Inhibitory and lytic effects of a nonionic surfactant on various asexual stages in the life cycle of *Pythium* and *Phytophthora* species. Phytopathology 77:112-114.
5. Tomlinson, J. A., and Faithfull, E. M. 1980. Effects of fungicides and surfactants on the zoospores of *Olpidium brassicae*. Ann. Appl. Biol. 93:13-19.
6. Tomlinson, J. A., and Thomas, B. J. 1986. Studies on melon necrotic spot virus disease of cucumber and on the control of the fungus vector (*Olpidium radicale*). Ann. Appl. Biol. 108:71-80.