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Spread of *Phytophthora* root and crown rot in *Saintpaulia*, *Gerbera* and *Spathiphyllum* pot plants in ebb-and-flow-systems

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Abstract

Spread of *Phytophthora* root and crown rot in three pot plant species was studied on ebb-and-flow benches where the nutrient solution was recirculated. The plant species and their respective pathogens were: *Saintpaulia ionantha* – *P. nicotianae*, *Gerbera jamesonii* – *P. cryptogea*, and *Spathiphyllum wallissii* – *Phytophthora* spp. Ebb-and-flow benches were infested with the pathogen using different methods: 18–25% of the plants on a bench were inoculated or potted in soil infested with the pathogen or the nutrient solution was infested by either zoospores or mycelium fragments. More than 80% of the inoculated *Saintpaulia* plants and 22% of plants potted in infested soil developed disease but no spread of the disease was observed. Infestation of the nutrient solution did not result in any diseased *Saintpaulia* plant. More than 70% of the *Gerbera* plants developed disease as a result of spread of the pathogen irrespective of the infestation method used. No significant spread of the disease was observed with inoculated *Spathiphyllum* plants nor from plants potted in infested soil. A few *Spathiphyllum* plants developed disease symptoms after infestation of the nutrient solution with zoospores. In one experiment, nearly all *Spathiphyllum* plants were diseased after infestation of the nutrient solution with mycelium fragments. The presence of an irrigation mat significantly reduced the spread of the *Phytophthora* disease in *Gerbera* and *Spathiphyllum*. The possibility of an irrigation mat acting as a filter for zoospores is discussed.

Introduction

In Dutch glasshouses, many pot plants are grown in ebb-and-flow systems where the nutrient solution is recirculated. In such systems potted plants are placed on benches or floors which are periodically flooded with nutrient solution. After a specified time, the nutrient solution is drained away and stored in tanks for recycling. Labour time for watering the pots is saved and recirculation of the nutrient solution prevents pollution of the enviroment with fertilizers and pesticides. A disadvantage of these systems is, however, the enhanced risk of spread of pathogens causing root diseases. Inoculum may leach out from pots contaminated with a pathogen and may easily be transferred with the nutrient solution to other pots. Inoculum in the nutrient solution may also originate from contaminated benches or tanks. The risk of spread of a disease may depend on the inoculum source and vary among pathogens. Transmission from contaminated pots with diseased plants has been shown for *Phytophthora cryptogea* Pethybr. and Lafferty in *Gerbera* (*Gerbera jamesonii* H. Bolus ex J.D. Hook), *P. parasitica* in vinca (*Catharanthus roseus* L.) G. Don, and *Pythium aphanidermatum* in poinsettia (Hoitink et al., 1992; Strong et al., 1997; Thinggaard and Andersen, 1995). Sonogo and Moorman (1993) found no or sporadic transmission of *Pythium aphanidermatum* (Edson) Fitzp. in cucumber in soilless medium when plants growing in medium infested with the pathogen had been placed in the system. However, they found consistent transmission of *Pythium aphanidermatum* when the irrigation water had been infested with mycelium of the pathogen. Cultural practices may also influence the degree of transmission. Some growers use irrigation mats on the bottom of their ebb-and-flow benches

or floors. The presence of a mat will result in a moist bottom of the bench or floor during prolonged periods of time and such moist conditions may favour survival of *Phytophthora* propagules on the bench or floor. An irrigation mat may, however, also reduce transmission of propagules by acting as a filter.

Phytophthora root rot is a serious disease in several pot plants in the Netherlands, especially of *Saintpaulia ionantha* Herm. Wendl. caused by *P. nicotianae* Breda de Haan, *Gerbera jamesonii* caused by *P. cryptogea* and *Spathiphyllum wallisii* caused by several *Phytophthora* species (Man in 't Veld et al., 1998). Thinggaard and Andersen (1995) have shown that *P. cryptogea* can easily be transmitted from infected *Gerbera* plants. For the other two pot plant species, it is not known whether *Phytophthora* can be transmitted with the nutrient solution. Knowledge of the epidemiology of root diseases in ebb-and-flow systems is important to inform growers about the risk of disease spread and to develop strategies to control the disease. Therefore, in the present study, the spread of *Phytophthora* root and crown rot in *Gerbera*, *Saintpaulia* and *Spathiphyllum* was studied in ebb-and-flow systems. *Phytophthora* rot of *Gerbera* was included to enable comparison with the study of Thinggaard and Andersen (1995). Inoculum of the pathogens was applied in different ways and the effect of the presence of an irrigation mat on spread of the *Phytophthora* diseases was studied.

Materials and methods

Plant species and pathogens

Plantlets of *Saintpaulia ionantha* cv. Emi (Expt I) and cv. Sonja (Expt II), *Spathiphyllum wallisii* cv. Ceres and *Gerbera jamesonii* cv. Sardana were obtained from commercial nurseries. Plantlets were potted in peat-based soil with 15% perlite (EGO Flus-fijn, Bleiswijk, the Netherlands) in pots with diameters of 9, 13 and 13 cm, respectively. Pots had a flat bottom with a 1 mm high ridge. One isolate of *P. nicotianae* isolated from *Saintpaulia* and one *P. cryptogea* isolate originating from *Gerbera* were used throughout the whole study. Two isolates (PD91/458 and AN97/22) of unknown *Phytophthora* species both originating from *Spathiphyllum* were used in experiments with this plant.

Table 1. Concentrations of macro-elements (mmol L^{-1}), electrical conductivity (EC), and pH of the nutrient solutions used for the three plant species

Macro-element	Plant species		
	Saintpaulia ionantha	*Gerbera jamesonii*	*Spathiphyllum wallisii*
NH_4	0.8	1.1	1.4
K	4.3	6.7	7.3
Ca	2.3	3.7	4.0
Mg	0.6	0.9	1.0
NO_3	8.6	13.1	14.1
SO_4	0.9	1.2	1.3
P	0.6	1.5	2.0
EC (mS cm^{-1})	1.1	1.7	2.2
pH	5.5	5.5	5.5

Greenhouse sites and ebb-and-flow benches

The first experiments were performed in a greenhouse in Aalsmeer (the Netherlands) with 48 ebb-and-flow benches. The benches were 1.3 × 1.8 m and each bench had a nutrient solution tank of 275 L. The benches had grooves on the bottom. Later experiments were performed in a greenhouse in Naaldwijk (the Netherlands) with 24 benches each of 1.0 × 2.2 m with a flat bottom and a nutrient solution tank of 150 L. Every week, tanks were supplemented with fresh nutrient solution. Plants were irrigated daily for 10 min during the first two weeks after infestation/inoculation and every second day after that in the experiments performed in Aalsmeer. In Naaldwijk, plants were irrigated every second day during the whole experiment. During irrigation, a 2 cm water level was reached on the benches. Nutrient solutions were made with rain water. Concentrations of macro-elements in the nutrient solutions prepared for the different plant species are shown in Table 1. Concentrations of micro-elements were the same in each nutrient solution: 15 μmol Fe, 5 μmol Mn, 3 μmol Zn, 10 μmol B, 0.5 μmol Cu, and 0.5 μmol Mo per L. The temperature in the glasshouse was set at 21 °C and ventilation at 22 °C.

Inoculum production and infestation

Two kinds of inoculum, mycelium fragments and zoospores, were produced. Mycelium fragments were produced by culturing the isolates on PDA for 2–3 weeks and homogenizing the cultures in tap water in a Waring blender for 20 s at high speed. Zoospores were produced by growing the isolates in V8 for 1–2 weeks,

Table 2. Different methods used to infest the ebb-and-flow benches with *Phytophthora* spp.

Method	Description
I. Plant inoculation	Plants on the middle of a bench were inoculated by pouring 50 ml of a suspension of homogenized culture plates (PDA) on the soil around the plant
II. Soil infestation	Plants were potted in infested soil and placed on the middle of a bench. Infested soil was obtained by mixing soil (3–5% v/v) from pots with diseased plants with fresh potting soil
III. Zoospores in tank	A zoospore suspension was poured into the nutrient solution tank 0.5 h before irrigation
IV. Zoospores on bench	A zoospore suspension was poured onto the middle of a bench at time of irrigation
V. Mycelium in tank	A mycelium suspension obtained by blending PDA-cultures in water was applied into the nutrient solution tank 0.5 h before irrigation

washing the mycelium in deionized water followed by incubation of the mycelium in nonsterile nutrient solution for 1 week. Zoospores were induced to release by incubation of the plates at 4 °C for 30 min, followed by 30 min at room temperature. Inoculum was applied in different ways as described in Table 2. Nutrient solution tanks were always filled just before infestation with the pathogen. Inoculum was applied 2 weeks after potting unless stated otherwise.

Experiments

Saintpaulia ionantha – P. nicotianae. Two experiments were performed. Experiment I (*Saintpaulia* Expt I) was located in Aalsmeer with 80 pots per ebb-and-flow bench (Figure 1). Expt I had a factorial design with a total of 10 treatment combinations (Table 3). The experimental factors were the inoculation/infestation method and the presence or absence of an irrigation mat on the bottom of a bench (0.5 cm thick, 250 gm^{-2}, Bevloeiingsmat Bont, Agrifirm, Bleiswijk, The Netherlands). These mats consist of a thin layer of polyethylene (bottom side) with a thicker layer made from polypropylene and acryl (upper side). Each treatment combination had four replicates. One replicate consisted of an ebb-and-flow bench with a nutrient solution tank separated from the other benches. The experiment ended 6 weeks after infestation/inoculation. Experiment II (*Saintpaulia* Expt II) was located in Naaldwijk with 78 pots per bench. The experiment had four different treatments consisting of a noninfested control and three infestation/inoculation methods (Table 3, Figure 1). The experiment ended 9 weeks after application of the inoculum.

Gerbera – P. cryptogea. (Location: Aalsmeer, *Gerbera* Expt III) Forty pots were placed on each bench (Figure 1). A factorial experiment was performed with inoculation/infestation method and presence/absence of an irrigation mat as the experimental factors (Table 3). The experiment had 12 treatment combinations including two noninfested controls (with and without an irrigation mat). Inoculum was applied 5 weeks after potting and the experiment ended 5 weeks later.

Spathiphyllum – P. spp. *Spathiphyllum* Expt IV was performed in Aalsmeer with *Phytophthora* sp. isolate PD91/458 and 40 pots per bench. (Figure 1). The experiment had a factorial design with inoculation/infestation method and the presence/absence of an irrigation mat on the bottom of a bench as the experimental factors (Table 3). The experiment had 10 treatment combinations including two noninfested controls (with and without an irrigation mat). Inoculum was applied 3 weeks after potting and last observations were done 12 weeks later. Two single factor experiments were perfomed in Naaldwijk with *Phytophthora* sp. isolate AN97/22 (*Spath* Expts V and VI) and 44 pots per bench (Figure 1). Expt V had two treatments: a noninfested control and 'plant inoculation'. In Expt VI five treatments were included (Table 3, Figure 1). Expts V and VI ended 12 and 16 weeks after the first application of the inoculum, respectively.

Observations and detection of Phytophthora

In all experiments the number of plants showing crown rot and their position on the table were determined weekly. At the end of *Saintpaulia* Expt II and *Spathiphyllum* Expts V and VI soil samples were taken from pots for detection of the *Phytophthora* pathogen. Six or four (*Spath* Expt VI) randomly chosen pots with plants without any visible above ground disease symptoms were sampled from each bench. Soil samples including roots were taken from the bottom side of each of these pots. The bottom of each pot was cut open and 30 ml of soil including root pieces near the holes of the pot was sampled.

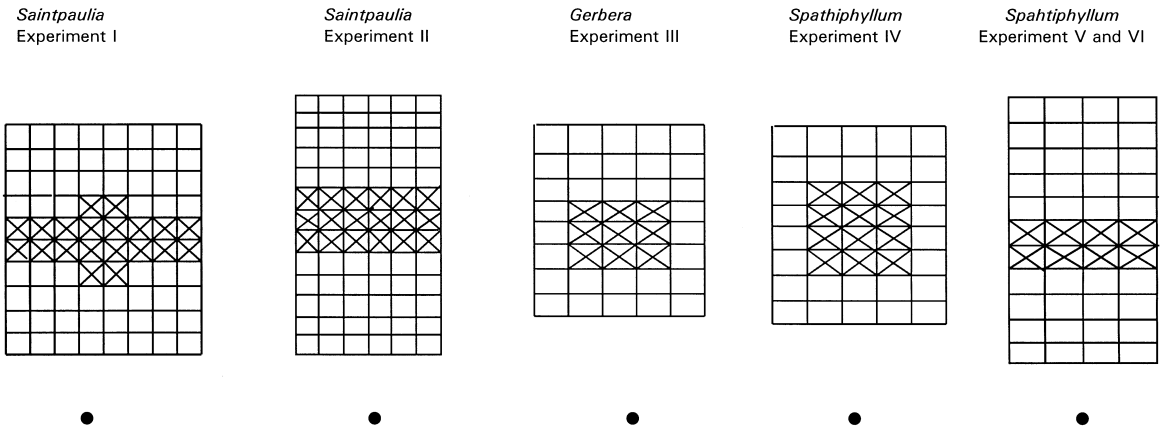

Figure 1. Site of plants on ebb-and-flow benches inoculated with *Phytophthora* spp. or potted in soil infested with the pathogen in different experiments with *Saintpaulia, Gerbera* or *Spathiphyllum*. Each quadrat represents a pot. Distances between pots were 6–12 cm. An (×) indicates an inoculated plant or pot with infested soil. A (•) indicates the site of the water outlet from which the benches were flooded.

Table 3. Summary of the ebb-and-flow experiments conducted with three pot plant species and different *Phytophthora* spp.

Experiment	Host plant	Pathogen	Irrigation mat[a]	Inoculation/infestation method[b]	Inoculum/infestation level
I	*Saintpaulia*	*P. nicotianae*	Yes	Plant inoculation	20/80 plants[c]
				Soil infestation	20/80 pots[c]
				Zoospores in tank	24 ml^{-1}
				Mycelium in tank	0.1 plate L^{-1}
II	*Saintpaulia*	*P. nicotianae*	No	Plant inoculation	18/78 plants
				Zoospores in tank	7×10^2 ml^{-1}
				Mycelium in tank	0.1 plate L^{-1}
III	*Gerbera*	*P. cryptogea*	Yes	Plant inoculation	9/40 plants
				Soil infestation	9/40 pots
				Zoospores in tank	1×10^3 ml^{-1}
				Zoospores on bench	1×10^3 ml^{-1}
				Mycelium in tank	0.1 plate L^{-1}
IV	*Spathiphyllum*	*P.* sp. PD91/458	Yes	Plant inoculation	9/40 plants
				Soil infestation	9/40 pots
				Zoospores in tank	24 ml^{-1}
				Mycelium in tank	0.1 plate L^{-1}
V	*Spathiphyllum*	*P.* sp. AN97/22	No	Plant inoculation	8/44 plants
VI	*Spathiphyllum*	*P.* sp. AN97/22	No	Plant inoculation	8/44 plants
				Zoospores in tank, 2 weeks after potting	1×10^3 ml^{-1}
				Zoospores in tank, 6 weeks after potting	1×10^3 ml^{-1}
				Mycelium in tank	0.1 plate L^{-1}

[a]Yes: the presence/absence of an irrigation mat was included as an experimental factor.
[b]Inoculation/infestation methods are described in Table 2. In each experiment a noninfested control was included.
[c]Number of plants or pots inoculated or infested/total number of plants or pots on an ebb-and-flow bench.

Samples were also taken from pots with diseased or dead plants which had been inoculated. These pots were sampled from the bottom as described above and a 30-ml sample was also taken from the upper 2 cm of soil directly adjacent to the diseased/dead plant. Four pots per bench with inoculated plants were sampled this way. From each bench, each pot with a diseased or dead plant which had not been inoculated was sampled the same way as pots with inoculated plants.

Each soil sample was placed in a plastic beaker with an inner diameter of 5 cm and filled with water till the water level was 2–3 cm above the soil level. Five *Rhododendron* leaf punches (6 mm in diameter) were added and beakers were incubated at 21–23 °C. After four days the leaf baits were placed on a *Phytophthora* selective medium (Tsao and Guy, 1977) and incubated at 24 °C. After 5–7 days baits were examined for outgrowth of the *Phytophthora* pathogen.

Effect of the position of inoculum in a pot on release of infective propagules

The effect of the position of inoculum in a pot on release of infective propagules into the nutrient solution was investigated by placing soil infested with *P.* sp. isolate AN97/22 at different heigths in a pot. The infested soil was obtained from pots with diseased plants and included diseased root pieces. A layer of infested soil, 3 cm thick, was placed either on the bottom, in the middle or in the upper part of a pot 9 cm high. Infested soil in the upper or middle part of a pot was placed on cheese cloth in order to decrease the risk of movement of infested soil to lower layers. Each pot was placed in a 2 cm layer of nutrient solution in a plastic box (12 × 16 cm). Controls were noninfested pots and cheese cloth bags with 30 ml of infested or noninfested soil. Five *Rhododendron* baits (leaf punches, 6 mm diameter) were added to the nutrient solution in each box. Pots and cheese cloth bags were gently lifted and removed after 24 h. The leaf baits were left in the nutrient solution for another 3 days after which they were placed on a selective medium and observed for outgrowth of *Phytophthora* after 7 days of incubation at 24 °C. The experiment was performed with eight replicates.

Data analysis

Experiments had a completely randomized design. Four replicate benches per treatment were used in each ebb-and-flow experiment. The percent of diseased plants of the noninoculated/infested plants/pots were computed and used to analyse the effect of the different treatment factors on spread of the *Phytophthora* disease. Percent data of the *Gerbera* Expt III were tested for normality and homogeneity of variances using the Shapiro–Wilk test and residual plot (Fry, 1993). The data were subsequently subjected to a two-way ANOVA, with inoculation method and presence/absence of a mat as experimental factors. Treatments resulting in 0 or 100% values only, having thus zero variance, were excluded from the analysis since they would violate the assumption of homogeneity of variance. In *Spath* Expt IV the effect of irrigation mat was tested by comparing the percent diseased plants for each inoculation method using a t-test ($P < 0.05$).

Results

Saintpaulia ionantha – P. nicotianae

Expt I: No spread of the disease was observed from diseased plants which had been inoculated or potted in infested soil as no plants which had not been inoculated or potted in infested soil developed disease (Table 4). No plants developed disease after infestation of the nutrient solution with zoospores. One diseased plant was observed on a bench with mycelium infested nutrient solution and one on a noninfested control bench. The other control and mycelium infested benches had no diseased plants.

Expt II: No spread of the *Phytophthora* disease was observed with any of the inoculation/infestation methods (Table 4). *P. nicotianae* was not detected in soil samples taken from the bottom side of pots, neither from pots with inoculated plants nor from pots with noninoculated plants. The pathogen was detected in soil samples taken from the upper 2 cm from five pots with inoculated plants.

Gerbera jamesonii – P. cryptogea

Expt III: In each treatment, except the control, *Phytophthora* root and crown rot spread in the system. The presence of an irrigation mat reduced the spread of the disease significantly except for the treatment where mycelium had been applied into the tank or zoospores onto the bench (F-test for irrigation mat × infestation method significant at $P < 0.001$) (Tables 4 and 5).

Spathiphyllum wallisi – P. spp.

Expt IV: No spread of disease was observed from pots with inoculated plants nor from pots with infested soil (Table 4). Diseased plants were observed after infestation of the nutrient solution with either

Table 4. Percentage of the inoculated plants (plant inoculation) and plants potted in infested soil (soil infestation) which developed disease in the different experiments with *Phytophthora* spp.

Experiment	Host plant	Inoculation/infestation method[a]	% diseased/dead plants		Spread[b]
			Mean	Standard error	
I	*Saintpaulia*	Plant inoculation	83.1	15.1	No
		Soil infestation	21.9	16.5	No
II	*Saintpaulia*	Plant inoculation	87.5	3.5	No
III	*Gerbera*	Plant inoculation	100.0	0.0	Yes
		Soil infestation	100.0	0.0	Yes
IV	*Spathiphyllum*	Plant inoculation	33.3	7.7	No
		Soil infestation	35.5	7.7	No
V	*Spathiphyllum*	Plant inoculation	71.9	12.9	No
VI	*Spathiphyllum*	Plant inoculation	84.4	7.9	No

[a]Methods are described in Table 2.
[b]Yes means that a significant percentage of plants which had not been inoculated nor potted in infested soil developed disease.

Table 5. Percent *Gerbera* plants with *Phytophthora* root and crown rot 5 weeks after inoculation/infestation with *Phytophthora cryptogea* on ebb-and-flow benches

Inoculation/ infestation method[b]	Percent diseased/dead plants[a]	
	Without irrigation mat	With irrigation mat
Control	0.0 (0.0) a[c]	0.0 (0.0) a
Plant inoculation	71.0 (12.5) a	22.6 (7.7) b
Soil infestation	94.4 (3.6) a	6.5 (4.0) b
Zoospores in tank	97.7 (5.8) a	68.8 (6.5) b
Zoospores on bench	97.5 (6.5) a	93.1 (3.7) a
Mycelium in tank	100.0 (0.0) a	100.0 (0.0) a

[a]Data are means of the noninoculated/infested plants/pots.
[c]Inoculation/infestation methods are described in Table 2.
[c]Values are means of four replicates. Values in parentheses are standard errors. Values in the same row followed by different letters are significantly different (t-test, $P < 0.05$).

Table 6. Percent *Spathiphyllum* plants with *Phytophthora* root and crown rot 12 weeks after inoculation/infestation with *Phytophthora* sp. PD91/458 on ebb-and-flow benches in Expt I

Inoculation/ infestation method[b]	Percent diseased/dead plants[a]	
	Without irrigation mat	With irrigation mat
Control	0.0 (0.0) a[c]	0.0 (0.0) a
Zoospores in tank	3.8 (1.3) a[c]	0.0 (0.0)a
Mycelium in tank	98.1 (1.9) a	12.5 (6.1)b

[a]Data are means of the noninoculated/infested plants/pots.
[b]Inoculation/infestation methods are described in Table 2.
[c]Values are means of four replicates. Values in parentheses are standard errors. Values in the same row followed by different letters are significantly different (t-test, $P < 0.05$).

zoospores or mycelium fragments. The presence of an irrigation mat significantly reduced spread of the *Phytophthora* disease (t -test, $P < 0.05$; Table 6). Expt V: No spread of disease was observed on the benches with inoculated plants (Table 4). *Phytophthora*. sp was detected in each soil sample taken from the upper 2 cm from 16 pots with inoculated plants and in samples taken from the bottom of three of these pots. The pathogen was not detected in pots with noninoculated plants.

Expt VI: No significant spread of the disease occurred on the benches with any of the inoculation/infestation methods (Table 4). On an average 0.7–2.2% of noninoculated plants developed disease symptoms on benches with infested nutrient solution, with inoculated plants and on the noninfested control benches. Isolations made at the end of the experiment failed to isolate the *Phytophthora* pathogen from these plants. At the end of the experiment, *Phytophthora.* sp. was detected in the upper 2 cm of soil in three out of the 16 sampled pots with inoculated plants. In two of these pots the pathogen was also isolated from the bottom samples. The pathogen was detected in bottom samples from two diseased plants on one bench in the 'mycelium-in-tank-treatment' and in one bottom sample from a plant without any above ground disease symptoms in the 'zoospores-after-6-weeks-treatment'. Each isolate showed the same mycelium type and colony morphology as the original isolate used to inoculate the plants and to infest the nutrient solution.

Effect of the position of inoculum in a pot on release of infective propagules

Phytophthora sp. was detected in the nutrient solution in each replicate of the treatments with infested soil on the bottom of a pot and with infested soil in a cheese cloth bag placed in the solution. The pathogen was not detected in the nutrient solution where infested soil had been placed in the middle or upper part of a pot.

Discussion

In the present study, spread of *Phytophthora* disease on ebb-and-flow benches was observed within the *Gerbera* – *P. cryptogea* system corroborating results from Thinggaard and Andersen (1995). Apparently, zoospores are released from infected *Gerbera* plants and also reach roots of other *Gerbera* plants through the nutrient solution. However, in the *Saintpaulia* – *P. nicotianae* system no spread of disease was observed. This great difference in the amount in which these diseases spread may be due to a difference in the amount of zoospore production between the two pathogens but may also be due to a difference in the position of the roots of the host plants and, thereby, the position of the pathogens in the pot. Roots of *Gerbera* plants reached the bottom of the pot within a few weeks and grew even outside the pot whereas roots of *Saintpaulia* reached the bottom of a pot only at the end of the cultivation period. The risk that zoospores will be released from infected *Saintpaulia* roots into the nutrient solution may, therefore, be low. Also, the risk that zoospores will reach an infection court during the cultivation period may be small because of the same reason, the absence of roots near the bottom of a pot. When pots with inoculated plants were placed in nutrient solution for 24 h the pathogen was never detected in the nutrient solution but the pathogen was isolated from soil from the upper parts of the pots (data not shown). Probably, the pathogen never reached the bottom of a pot. *P. nicotianae* could not be isolated from soil samples taken from the bottom site of pots with diseased plants at the end of the cultivation period in *Saintpaulia* Expt II. Generally, transmission of a root pathogen from an infected plant will only occur if infective propagules pass through the holes in the bottom of a pot. Therefore, the absence of the pathogen close to the bottom side of a pot probably indicates a low risk of contamination of the nutrient solution and thereby a low risk of spread of the disease.

The risk of spread of *Phytophthora* root and crown rot in *Spathiphyllum* is probably low in practice, as no spread of the disease was observed after inoculation of young plants on the middle of an ebb-and-flow bench. In practice, infected or contaminated plantlets are probably the primary inoculum source as potting soil must fulfill strict phytosanitary rules and growers always use new pots for each cultivation period in the Netherlands. In Expt VI, two noninoculated plants developed disease symptoms on benches with inoculated plants. It was unclear if this was due to spread of the *Phytophthora* pathogen from the inoculated plants. The two diseased (noninoculated) plants may have been contaminated or infected with a *Phytophthora* pathogen before the start of the experiment as on one of the control benches we also observed three diseased plants. These plants may have also died for other reasons than *Phytophthora* disease since isolations made at the end of the experiment failed to isolate *Phytophthora* from these plants.

Phytophthora sp. was detected near the bottom in some pots with inoculated *Spathiphyllum* plants at the end of Expts V and VI. In a small additional experiment, 10 pots with diseased plants were placed in nutrient solution for 24 h. We were able to isolate the *Phytophthora* pathogen from the nutrient solution of one pot. Apparently, infective propagules may be released from pots with diseased plants but the amount of inoculum is probably too small for high infection risks of other *Spathiphyllum* plants. Moreover, a commercial grower will remove diseased plants in an early stage and, thereby, reduce the risk of spread of the disease whereas we did not remove any diseased plant from the benches in our experiments.

A few diseased *Spathiphyllum* plants were obtained when the nutrient solution had been infested with zoospores. Most of the zoospores will probably encyst within one day after application as the duration of motility of zoospores of *Phytophthora* spp. in aqueous solutions usually does not exceed 24 h (Erwin and Ribeiro, 1996). It is, however, unknown how long the cysts will remain viable. It may be expected that the number of viable propagules will decrease rapidly within a few days and, thus, that the position of the roots in the pot at time of infestation/contamination may be critical for the chance of a propagule to reach an infection court. Therefore, more diseased plants may be expected if the nutrient solution is infested or contaminated in a later stage, especially when roots are present outside the holes of the bottoms of the pots.

The presence of an irrigation mat significantly reduced spread of *Phytophthora* rot in *Gerbera* when inoculum had been applied to pots or zoospores had been applied into the tanks (Table 5). Possibly, the irrigation mat reduced release of inoculum from pots and also the entry of infective propagules into pots from the nutrient solution. Pots had a ridge 1 mm high providing some space between the bottom of the pot and the bottom of the bench. However, when an irrigation mat was used the ridge sank into the mat by the weight of the filled pot resulting in lack of space between pot and mat. Therefore, the nutrient solution with the zoospores probably had to pass through the irrigation mat before entering the pot. A reduction in pathogen transmission by the presence of an irrigation mat may not be expected if pots are used which allow space between pot and mat, for example pots with high ridges or with grooves on the bottom. The reason that no reduction in spread of *Phytophthora* rot was found when zoospores had been applied onto the bench or mycelium into the nutrient tank was probably due to the high infection pressure obtained using these inoculation methods. These two methods resulted in nearly 100% diseased plants and some reduction in inoculum entry into the pots due to presence of an irrigation mat was probably not sufficient to reduce the number of diseased plants. It is not known whether infective propagules will accumulate in the irrigation mat and thus act as a source of inoculum in a successive crop. The possibility of an irrigation mat as a control strategy of root pathogens in ebb-flow systems will be further investigated.

Control measures to reduce losses in *Saintpaulia* and *Spathiphyllum* by *Phytophthora* rot should focus on early detection of the pathogen in propagation material and on inhibition of the pathogen in the pot, for example by disease suppressive substrates e.g. compost amended peat mixes (Hoitink et al., 1991). Control measures directed at the reduction of dispersal of the pathogen in the nutrient solution will be effective against *P. cryptogea* in *Gerbera*. Transmission of *Phytophthora* pathogens with the nutrient solution may be controlled by the presence of an irrigation mat, increased concentrations of minerals like calcium may negatively affect the viability of zoospores and/or the addition of (bio)surfactants to the nutrient solution (Stanghellini and Miller, 1997; Von Broembsen and Deacon, 1997).

In conclusion, the risk of spread of root diseases in ebb-and-flow systems may vary considerably among plant-pathosystems. In the present study, root rot in *Gerbera* caused by *P. cryptogea* spread considerably but no spread was observed of *Phytophthora* root and crown rot in *Saintpaulia.* With the *Spathiphyllum* – *Phytophthora* system no significant spread was observed from diseased plants. *Spathiphyllum* plants developed, however, disease symptoms after artificial infestation of the nutrient solution in one experiment.

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