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John A. Biernbaum
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FLOOD SUBIRRIGATION SYSTEMS FOR GREENHOUSE PRODUCTION AND THE POTENTIAL FOR DISEASE SPREAD

By

Renee Kay George

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ABSTRACT

FLOOD SUBIRRIGATION SYSTEMS FOR GREENHOUSE PRODUCTION AND THE POTENTIAL FOR DISEASE SPREAD

By

Renee Kay George

There was no significant difference between plant height, dry weight, flower number or postharvest quality of poinsettias 'Gutbier V-14 Glory' (*Euphorbia pulcherrima*) or Easter Lily 'Nellie White' (*Lilium longiflorum*) when grown using topwatering or flood subirrigation.

Geraniums (*Pelargonium X hortorum* L.H. Bailey 'Ringo Scarlet') were grown in trays which contained 3 non-inoculated plants and one plant inoculated with *Pythium ultimum* which were topwatered or subirrigated with recycled solution. Spread of P. ultimum occurred into water and into plants.

Geraniums inoculated with *P. aphanidermatum* were grown in trays which contained non-inoculated geraniums in either Baccto, Baccto drenched with metalaxyl or Naturally Suppressive Ball Growing Mix 2. There was no significant difference in spread of *P. aphanidermatum* between plants grown with either irrigation system or between plants grown in either media.

To my brother, Ronny, who through his mental retardation
has taught me more about life than all of my formal education.

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Guidance Committee:

The paper format was adopted for this thesis in accordance with departmental and university regulations. Sections I and II are to be submitted to Hortscience and Section III is to be submitted to Plant Disease.

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Literature Review

Flood Subirrigation Systems for Greenhouse Production and the Potential for Disease Spread

Subirrigation of plants with recirculated irrigation water and fertilizer solution is an important consideration as the greenhouse industry works to limit water and fertilizer runoff. While some cultural factors in the greenhouse have changed, the basic concepts of flood subirrigation have been around for many years. Flood subirrigation is becoming more popular as flood subirrigation systems become more economical and are recognized for their environmental benefits. One of the key issues deterring more growers from using flood subirrigation with recirculated solutions is the potential for pathogen dispersal with recirculated irrigation water.

History and types of subirrigation

E. C. Green and W. S. Turner used subirrigation almost a century ago for lettuce production in beds as an attempt to prevent lettuce rot (Green and Green, 1895). To test the theory that reducing the amount of water on the foliage would reduce rot, a few lettuce plants were placed in a box containing an irrigation tile. The plants were disease free so they enlarged the experiment to include other vegetable plants. After five years of research they concluded that subirrigation was superior to ordinary methods of irrigation for both bed and bench production.

Subirrigation is not mentioned again until 1940 when Post described a flood subirrigation method of container grown plants. Potted plants were placed on a watertight bench covered with gravel. Water was injected into

the gravel until the bottom one third to one half of the pot was submerged. When moisture was observed at the surface of the pot, the water was drained either into a tank for recycling or to a sewer.

Two types of constant water level irrigation were used by Seeley (1948) for a variety of crops. In one method the pots were plunged into a layer of sand, in the other method the plants were set on top of a layer of sand. For the constant water level subirrigation with the plants plunged in sand, pots of plants were submerged in a sand medium up to one inch below the top of the pot. This sand layer was in contact with a gravel bed saturated with water. Water moved from the gravel into the sand and into the pot by capillary action. Post and Seeley (1947) used the constant water level method to successfully grow roses.

In the other method the plants were placed on top of an inch of sand on top of the saturated gravel. All plants were surface watered to establish capillarity before placement on the constant water level benches. Both methods produced satisfactory results for poinsettias, geraniums, cineraria, begonia, and kalanchoe, except for those plants in which water touched the bottom of the pot (Seeley, 1948). These methods were not adapted in greenhouses presumably because of the difficulty in maintaining watertight benches and obtaining and moving the sand and gravel.

Another method of watering container plants from the bottom is the capillary mat. Originally plants were placed on a thin (2.5-4 cm) layer of sand which was irrigated with drip tubes. This method was replaced by synthetic mats in the early 1970's. (Hammer and Langhans, 1972). The capillary mat has been reported to produce quality plants including

chrysanthemum (Rosenbaum et al., 1979; Hammer and Langhans, 1972) and poinsettia (Freeman, 1974; Wilfret and Harbaugh, 1977). Some investigators report advanced plant growth, (Freeman, 1974) and earlier maturation, (Hammer and Langhans, 1972) while others report that poinsettias grown on capillary mats grew taller and remained vegetative longer (Wilfret and Harbaugh, 1977) than those poinsettias which were hand-watered. Subirrigation by capillary matting was widely used in Europe, where most flowering container plants are grown in three, four or five inch pots because it was more practical to use capillary mats than drip tubes with smaller pots (Kiplinger et al., 1975).

The first ebb and flow flood subirrigation benches were built in Denmark in 1976 (Hamrick, 1986). In ebb and flow flood subirrigation, a molded plastic tray on top of a bench frame is flooded with water. The water is left on the tray for a period of time so the plants can take up water by capillary action. The trays are then drained, usually into a holding tank, from which the solution may be recirculated. The difference between constant water level subirrigation or capillary mat irrigation and ebb and flow flood subirrigation is that in ebb and flow flood subirrigation the water is in direct contact with the pot.

Advantages of flood subirrigation

Ebb and flow flood subirrigation is an easy, economical way of irrigating container root media in a uniform manner. Conventional surface watering of plants is more time consuming and has a higher labor cost than flood subirrigation. Flood subirrigation provides more even watering than conventional drip tube watering, where blocked tubes are often a problem (Firth, 1986). Also with flood subirrigation there is less labor involved

in shipping and handling of the crop compared to drip tubes, because there are no drip tubes to remove or install (Ball, 1987). The humidity of the greenhouse is kept lower because plant leaves, walks and aisles do not get wet, as in conventional surface watering methods (Hamrick, 1986).

The interest in ebb and flow flood subirrigation has also increased due to an increase in awareness of groundwater contamination issues in the United States. The Environmental Protection Agency has made groundwater its number one priority (Hamrick, 1987). One way to reduce the amount of possible ground water contaminants released from a greenhouse is to reduce the gross amount of water used to produce the crop. In systems where the water is recirculated, water savings of up to 39% have been reported (Koch and Holcomb, 1983). In systems with constant liquid fertilizer, recycling leachate would also reduce the gross amount of nutrients applied and would reduce the potential for groundwater contamination. Many European growers using flood subirrigation recirculate their irrigation water (Ball, 1985).

Disadvantages of flood subirrigation

While flood subirrigation has many advantages, growers have also expressed concern over potential problems with flood subirrigation. Many of the concerns that growers have about flood subirrigation are the same as those raised with the first use of subirrigation in the 1890's, again during the 1940's and in the 1970's with the capillary mat. These concerns include the potential for salt accumulation in the upper layers of the pot, especially on a long term crop, due to the capillary movement of the water in the pot (Kiplinger et al., 1975; Koch and Holcomb, 1983) Many growers assume that to avoid this layer of soluble salts in the top

of the container they must leach with clear water at regular intervals which is time consuming and thus costly. Flood subirrigation may not be as flexible as growers would like, because the best quality is achieved when each bench is used for the same size pot, same crop and same media (Ball, 1987). It is difficult to have proper moisture for two different size pots on the same bench because the media will increase in dryness with an increase in the distance from the water to the top of the media (Seeley, 1948). Therefore the upper surface of a 15 cm pot will tend to be drier than the surface of a 10 cm pot on the same bench.

For proper drainage benches must be kept level. Solid plastic trays may also inhibit air movement around the plants, although there are trays with raised holes to provide air circulation even during flooding (Firth, 1986). The cost of flood subirrigation benches ranges from $3.75 - $4.00 per square foot for the flood benches and trays. The longevity of the plastic trays is questionable (Ball, 1987). With flood subirrigation trays there is concern about algae growth, as some investigators have reported this to be a problem with capillary mats, (Tayama, 1986) while others have reported no algae problems on mats in continuous use for over 12 months (Hannings, et al., 1974).

It is also necessary in a recirculating solution system to monitor and adjust the solution to insure the proper pH and soluble salts level (Firth, 1986). Another concern growers have is the potential for disease spread through recirculating the irrigation water (Aimone, 1984, Ball, 1985, Ball, 1987, Firth, 1986, Hamrick, 1986, Hamrick, 1987, Kiplinger et al., 1975, Koch and Holcomb, 1983).

Diseases

Koch and Holcomb (1983) witnessed no disease development in a subirrigation capillary mat system where the nutrient solution was not recirculated despite the wetness of the root medium nor in a system using capillary mats with recirculated water for the production of marigolds. In Europe, research has shown that re-using solutions that have passed the root zone, as in re-using water that has leached from a top watered plant, without disinfecting, resulted in a rapid spread of pathogens, compared to a low risk with flood subirrigation and aeroponics or NFT (Molitor, 1990). A limited number of growers in the United States have reported no problems with soil-borne disease in their flood subirrigation systems (Aimone, 1984; Ball, 1985; Firth, 1986; Hamrick, 1986) as long as good sanitation is practiced, such as cleaning and disinfecting benches between crops.

The vigor of the pathogen and its ability to cause disease is influenced by the availability of nutrients necessary for the stimulation of germination of the pathogen and its subsequent infection, colonization of and sporulation in plant tissue. The quantity of inoculum present is determined by the type of dormant structure the pathogen forms, and the ability of the inoculum to survive temperature and moisture extremes. Some spores of *Pythium*, for example have been found to survive for 12 years. The age of the inoculum can also influence its ability to infect plants (Hoppe, 1966).

The environment in which the host and pathogen grow can greatly influence infection by favoring either the host or the pathogen (Joiner, ed. 1981). Any environmental condition which stresses the host can

increase its susceptibility to disease. This includes stress from excessive levels of soluble salts from over-fertilization and stress from over- or under- watering, or under-fertilization. Different pathogens can also be favored at different moisture levels or temperatures. On soybeans, *Pythium aphanidermatum* was more virulent at 24 - 36°C while *P. debaryanum* and *P. ultimum* were more virulent at 15 - 20°C (Thomson et al., 1971). Susceptibility to pathogens can vary between cultivars. Hausbeck et al. (1988) showed that geranium cultivars varied in their susceptibility to *Pythium ultimum*. Individual isolates of each organism can also vary in virulence (McCarter and Littrell, 1970).

When considering the pathogen host interaction, it is important to realize that different pathogens penetrate plants in different ways. All plant pathogenic viruses and many bacteria enter plants through wounds; bacteria and certain fungi enter through natural plant openings; and many fungi are able to penetrate the intact surfaces of plants (Roberts and Boothroyd, 1984).

While there is no evidence of disease spread through a recirculating solution where an organic substrate is used to support the plant, there are many reports of disease spread through hydroponic systems (Bates and Stanghellini, 1982; Evans, 1979; Gold and Stanghellini, 1985; Jenkins and Averre, 1983; Molitor, 1990; Stanghellini and Russell, 1973; Stanghellini et al., 1984; Stanghellini et al.,1988) which, like flood subirrigation, include the recirculation of nutrient solution.

The growing of plants without soil or other organic media, commonly referred to as hydroponic culture, has been used in commercial production at least since the mid-1930's (Ellis and Swaney, 1938). Disease spread

through a system with the plants supported by an inert inorganic medium may be more likely to occur because organic growing media contain natural predators to many soil - borne fungi. These natural predators play an important role in the suppression of fungal development (Lawson and Dienelt, 1988). Disease development may be further suppressed in plants grown in an organic medium because they often have a higher oxygen level near the root zone than those grown hydroponically (Kiplinger, 1975; Lawson and Dienelt, 1988).

Pathogens known to attack hydroponically grown plants include species of the fungi *Pythium, Phytophthora, Fusarium, Colletotrichum*, and *Pyrenochaeta* and the bacteria *Erwinia* and *Corynebacterium* (Lawson and Dienelt, 1988). It is possible for bacteria such as *Xanthomonas sp., Erwinia sp. and Pseudomonas sp.* to be moved with water in any type of watering system. It is also possible for them to enter natural openings or wounds in the roots (Roberts and Boothroyd, 1984) There have, however, been no reports of serious bacterial disease in hydroponics due to their relative inability to infect roots when present in solution (Stanghellini, personal communication).

Some species of *Pythium* and *Phytophthora* have the greatest potential for disease spread in recirculated water because some of their spores are motile in water (Plaats-Niterink, 1981). *Pythium* can become a severe problem in mature plants grown in hydroponic systems if the fungus gets into the nutrient solution. Once one plant is infected and releases zoospores into the solution circulated to other plants, severe losses may occur (Rowe, 1986).

Pythium

Pythium spp. are widely distributed throughout the world. (Hendrix and Campbell, 1973). The most common long term survival structure of the fungus is the oospore, a thick walled spore that can survive a long time even under adverse conditions. These spores are easily distributed with soil particles moved by wind, machinery, or water (Stephens et al., 1983). These oospores can germinate to form mycelia which can infect plants. Depending on the species, the oospores may also form sporangia that give rise to many small, swimming zoospores, each of which may cause a separate infection (Hendrix and Campbell, 1973). These zoospores can move about in the water film surrounding soil particles (Rowe, 1986).

Once a plant is infected with *Pythium* the fungus will quickly colonize the tissues, causing a rapid breakdown of roots and succulent stems (Roberts and Boothroyd, 1984). Research in North Carolina (Rowe, 1986) showed that a transplant infected with *Pythium* can spread to other plants within a hydroponic system in less than one week. Disease losses may be quite severe, up to 100% loss in hydroponically produced tomatoes infected with *Pythium* (Lawson and Dienelt, 1988). The general disease of root rot is widely attributed to Pythium spp. One species of *Pythium* known to incite root rot in poinsettia and Easter lilies (*Lilium longiflorum*) and stem rot in geranium (*Pelargonium hortorum*), is *Pythium ultimum* (Scheffer and Haney, 1940, Miller and Sauve, 1979). Different species of *Pythium* have varying environmental conditions which favor their growth and ability to infect plants. Temperatures between 10 - 20 °C are most favorable for oospore production in *Pythium ultimum*. Oospores are dormant at first but over time become increasingly germinable.

Germination can exceed 90% after contact with soil extract for three weeks (Ayers and Lumsden, 1975). *P. ultimum* was more virulent in infecting soybean seedlings at 15 - 20 °C or after preconditioning at 4, 8, or 12°C for more than four days than at 22.5-36°C (Thompson et al., 1971). Both plant age and mycelia age can affect the virulence of *Pythium ultimum*. Nearly 100% of soybean seedlings 8 - 10 days old were killed with 4 to 8 day old mycelium. The percentage killed decreased as the mycelium age and/or the plant age increased (Laviolette and Athow, 1971). Snapdragon (*Antirrhinum majus*) seedlings less than 15 days old were killed within 6 days when infected by *Pythium ultimum* . However, plants 25 days old or older tolerated the infection and completed their life cycle, with a decreased tolerance for heat stress as the only visible symptom (Mellano et al., 1970). Soil amendments can also influence germination of *Pythium ultimum* sporangia, with soils amended with sodium nitrate, sodium nitrite, ammonium nitrate and urea inhibiting germination (Agnihotri and Vaartaja, 1967). Sporangia germination in *Pythium ultimum* increases with increasing soil moisture and is highest in soil temperatures between 15 and 25°C (Agnihotri and Vaartaja, 1967).

Disease assessment and management

There are many cultural practices which can greatly reduce the risk of disease problems with recirculated water systems. The same sanitation practices which apply to topwatering apply to hydroponics and flood subirrigation. Growers could use pathogen free stock, and disinfest benches, pots and greenhouse floors. The pH and soluble salts content of the media should be carefully monitored to be sure they are in the range most favorable for plant growth. Media that is well aerated could be used

and irrigations could be scheduled based on plant water usage to avoid extremes in soil moisture. Growers should know the pathogens which may cause disease on their crop, and the type of environment which favors them (Rowe, 1988).

An important concern with recirculated water is that there are currently no fungicides labelled for use in recirculated irrigation systems. The effect of low doses of fungicide within the flood subirrigation system is not known. The efficacy of an initial fungicide drench at planting may be prolonged due to the absence of leaching, but has not been demonstrated.

There are now commercially available *Pythium* suppressive media, (Ball Growing Mix 2, Ball Seed Co., West Chicago, IL), which contain composted hardwood bark which has been shown to have fungicidal properties (Daft et al., 1979, Hoitink, 1980, Stephens et al., 1981, Chen et al.,1987, Chen et al., 1988). Other forms of biocontrol include incorporation of competitive organisms such as *Streptomyces sp.* or *Trichoderma sp.*, which have produced varying amounts of control (Gregory et al., 1952, Bolton, 1978). With flood subirrigation, biocontrol may be more effective as the absence of leaching may provide a more favorable environment for the establishment of organisms antagonistic to plant pathogens.

Another problem of disease management in any of these irrigation systems is identifying the presence of pathogens in the water. Gill (1970) sampled irrigation ponds using susceptible plants floating in styrofoam boards to trap *Pythium*. Lemons (Klotz et al., 1959), lemon leaves and Millipore filters (Thomson and Allen, 1974) have been used to

trap *Phytophthora*. There are companies which are currently formulating quick antibody immunoassay kits for early detection of specific plant diseases (Agri-Diagnostics, Cinnaminson, NJ).

Methods for treating water before recirculating include treating with ozone, chlorine or bromine (Hamrick, 1987). In hydroponic systems, ultraviolet irradiation of the recirculating solution has been used to control root rot of spinach caused by *Pythium*. Because iron is destroyed by ultraviolet irradiation, it must be added to the system following each irradiation (Stanghellini et al.,1984). The addition of a surfactant (Agral) was effective in reducing the number of zoospores produced by *Olpidium radicale*, the fungal vector of lettuce big vein disease (Tomlinson and Thomas, 1986). Methods that work well in hydroponics may not work as well nor be economical in systems which use organic media. Some growers currently using flood subirrigation with recirculated nutrients have had success in chlorinating their irrigation water or treating it with bromine (Agribrom, Great Lakes Chemical Co., West Lafayette, IN).

Research objectives and goals

The overall objectives of this research were to investigate the potential for salt accumulation and the potential for disease spread in flood subirrigated pot plants. Experiments were done with poinsettias and Easter lilies to compare water use and plant growth with subirrigation and topwatering. Geraniums were grown to investigate the disease spread in topwatering where the leachate is recirculated and in flood subirrigation with recirculated solutions as a model system for *Pythium* infection of geraniums had been established (Hausbeck et al., 1988).

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Section I HortScience Subject Category: Production and Culture

Comparison of growth and water use of poinsettia and Easter lily with topwatering and flood subirrigation.

Renee K. George, John A. Biernbaum, Royal Heins, and Christine Stephens*

Department of Horticulture, Michigan State University, East Lansing, MI 48824

*Department of Botany and Plant Pathology, Michigan State University, East Lansing, MI 48824

Additional Index Words: Euphorbia pulcherrima, Lilium longiflorum, soluble salts, fertilizer.

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Abstract. Poinsettia 'Gutbier V-14 Glory" (Euphorbia pulcherrima) and Easter Lily 'Nellie White' (Lilium longiflorum) were grown using traditional topwatering methods (hose or drip emitters) or subirrigation by flooding with recirculated solutions. Subirrigation of poinsettias with the same nutrient solution recommended for constant liquid fertilizer levels for topwatering resulted in an accumulation of soluble salts to 4.0 mS (saturated media extract) in the root zone. The fertilizer rate for the subirrigated poinsettias was reduced from 350 mg liter^{-1} to 250 mg liter^{-1} on 1 Nov. Poinsettia plant height, dry weight, bract size and number, and post harvest keeping quality were not influenced by irrigation method. There was no significant difference in the results of biweekly root media analysis for the poinsettias but there were small but statistically significant differences in the poinsettia leaf tissue analysis for P, Ca, and Mo. Approximately 40% of the water applied was not utilized by the crop with topwatering. There was no significant difference in plant height, fresh weight, dry weight, days to flower, number of flower buds, root quality, and postharvest keeping quality between Easter lilies subirrigated with 100 mg liter^{-1} constant liquid fertilizer and those topwatered with 200 mg liter^{-1} constant liquid fertilizer. In the Easter lily root media the EC, N, K and Mg were significantly higher in the drip emitter treatment, but there was no significant difference in the results of the leaf tissue analysis.

Limiting water and fertilizer use and the nitrate effluent from greenhouses is important to prevent surface water and groundwater contamination. In many commercial greenhouses water and fertilizer are applied to excess, with the drainage water percolating into the greenhouse floor or moving away from the greenhouse in drainage tiles.

Flood subirrigation with recirculated nutrient solutions is widely used in greenhouses in Denmark and the Netherlands for a variety of flowering container plants including kalanchoe, roses and begonias. Flood subirrigation is beginning to be used in the United States. The amount of water and fertilizer used is minimized and can be closely monitored. Flood subirrigation has advantages other than preventing runoff and saving water and fertilizer. With subirrigation water is more evenly distributed, large numbers of small pots can be watered easily, and less labor is required for watering and handling plants. The use of subirrigation can lower the humidity of the greenhouse because plant leaves, walks and aisles do not get wet (Green and Green, 1895; Post, 1940; Seeley, 1948; Colacello, 1949; Bunt, 1988).

Our objectives were to quantify the water and fertilizer use with topwatering and subirrigation with poinsettias and Easter lilies and to investigate fertilization and irrigation practices with subirrigation by flooding with recirculated nutrient solutions.

Poinsettia (Euphorbia pulcherrima 'Gutbier V-14 Glory') cuttings were potted in 15 cm azalea (1250 cm^3) pots on 21 August, 1987. Treatments were initiated on 2 October, 1987 and the experiment was terminated 18 December, 1987. Three irrigation treatments consisted of subirrigation, hand watering with a hose and breaker and drip emitters

(Chapin Watermatics, Watertown, NY). Each treatment consisted of one bench with forty five plants per bench. All three benches were in a glass greenhouse. All treatments initially received 350 mg liter^{-1} of N (87.5% NO_3-N) and K from KNO_3, $Ca(NO_3)_2$, and NH_4NO_3 at each irrigation. The electrical conductivity (EC) of the irrigation water without any added fertilizer was 0.65 to 0.70 mS. The EC of the initial nutrient solution was 2.70 mS. Root media samples were analyzed by the MSU Soil Testing Laboratory (East Lansing, MI) every two weeks. Four weeks after the treatments began, which coincided with the beginning of bract color development, the EC level in the root media of the subirrigated plants reached 4.0 mS measured by saturated media extract (SME) root media analysis. At this time all plants were leached with 600 ml of S.T.E.M., (soluble trace element fertilizer, 60 mg liter^{-1}, Peters, Fogelsburg, PA) and $MgSO_4$ (60 mg liter^{-1}) solution. The subirrigation tank was diluted with water by 45% of its volume changing the EC from 2.87 mS to 1.77 mS. The stock solution for all treatments was changed to 250 mg liter^{-1} N by the deletion of the NH_4NO_3. Phosphoric acid (85%, 0.40 ml liter^{-1}) was added to lower the nutrient solution pH. The new fertilizer solution for the drip emitters and hand watering had an EC of 1.7 mS and a pH of 5.5. Fertilization was discontinued on 27 November.

At the termination of the experiment, root media was partitioned into three sections, approximately 3 cm in depth, and analyzed by the MSU Soil Testing Laboratory with the SME method. Plant height, bract number and bract width were recorded at this time. The most recently expanded green leaves were collected for tissue analysis and the remaining plant material was oven dried for dry weights (60°C for 48 hours).

Easter Lily (Lilium longiflorum 'Nellie White') bulbs were potted on 12 October, 1987 in 15 cm (1500 cm^3) standard pots. Pots were held in a greenhouse at 22°C for two weeks, then in a cooler at 5°C for six weeks. Plants were drenched with 10 mg $liter^{-1}$ metalaxyl (Subdue, Ciba Geigy, Greensboro, NC) and 60 mg $liter^{-1}$ benomyl (Benlate, DuPont, Wilmington DE) on 17 October, 18 December and 15 January. A wetting agent was applied to all plants 1500 mg $liter^{-1}$ (Aqua-Gro, Aquatrols Corporation of America, Pennsauken, NJ) on 3 Mar 1988.

Pots were moved to the greenhouse on 17 December. Irrigation treatments were initiated 2 January, 1988 and the experiment was terminated 31 March, 1988. There were two irrigation treatments, subirrigation with recirculated fertilizer solution and drip emitters. There were two replicates of each treatment with 50 plants per replicate. The subirrigation treatments were fertilized with 100 mg $liter^{-1}$ N (87.5% NO_3-N) and K, and the topwatering treatments with 200 mg $liter^{-1}$ N and K from KNO_3, $Ca(NO_3)_2$, and NH_4NO_3. The EC of the nutrient solution was 1.4 mS for the subirrigation treatments and 1.7 mS for the topwatering treatments. Root media samples were analyzed by the MSU Soil Testing Laboratory every two weeks with SME. Leaf tissue samples were taken every two weeks beginning 4 February. A 5 g fresh weight sample of the most recently fully expanded leaves of randomly selected plants constituted a sample.

A commercially available peat based soilless mix was used for both experiments. (Baccto Professional Growers Mix, Michigan Peat, Houston, TX). All plants were grown on subirrigation benches 1.8 m wide by 3 m long (Campbell·O'Brien Ltd, Georgetown, Ontario). Each subirrigation treatment

had an independent 200 liter reservoir. At each irrigation submersible pumps (Little Giant Model NK-1) within each reservoir ran for 10 minutes, filling the bench to an approximate depth of 2 cm, using 150 liters of solution. It took approximately 30 minutes for the nutrient solution to drain back into the reservoir. The fertilizer solution retained by the pots was measured and replaced after each irrigation. The amount of water held by the pots was estimated by subtracting the amount of water left on the bench with no pots present from the amount replaced. Five plants per replicate were weighed before and after irrigation. The difference of these weights was also used as an estimate of water use.

Topwatering treatments were grown on the same benches to facilitate the collection of leachate. Total water applied was estimated by measuring the length of time of application and the flow rate of the fertilizer solution as it was applied by either drip emitters or hose and breaker. Percent waste was calculated by dividing amount collected as leachate by the total applied. These estimates would vary based on amount of leaching fraction allowed. The amount of leaching was comparable to observed grower practices, with a leaching fraction of 30% for the poinsettias and 45% for the Easter lilies. The drip emitters ran for 5-8 minutes at 55 ml pot^{-1} min^{-1} for the poinsettias and 4-6 minutes at 140 ml pot^{-1} min^{-1} for the Easter lilies.

Plants from both experiments were placed in a simulated post harvest environment at 22°C with 0.7 μmols m^{-2} s^{-1} from cool white fluorescent lights for 24 hours per day. All plants were topwatered.

Analysis of variance was performed by BMDP 2V PC software. When the F test was significant means were separated by LSD.

Poinsettias. There was no significant difference in plant height, bract number, bract width, nor in bract, stem and leaf dry weight between irrigation methods. There was no significant difference in the results of biweekly root media analysis averaged over the experiment (Table 1). The EC and the nutrient content was significantly different in the partitioned root media (Table 2). In the upper layer of media the EC and all elements tested, except P, were 2-3 times higher than the reported optimum (Warncke and Krauskopf, 1983). The macro nutrients analyzed accounted for 58% of the total estimated soluble salts (EC x 700). There were small but statistically significant differences in the leaf tissue content of P, Ca and Mo (Table 3). The leaf tissue content of Ca was lower in the subirrigated treatment while the leaf tissue content of Mo was higher in the subirrigated plants. The leaf tissue content of P for the subirrigated plants was higher than the leaf tissue P content of plants irrigated with drip emitters but lower than the leaf tissue content of those plants irrigated by hand.

The water waste for the hand watering with hose and breaker was 43% over 10 irrigations. The waste water in this treatment consisted of leachate and fertilizer solution lost between pots. The average EC of the hand watering leachate was 3.3 mS when the fertilizer concentration was 350 mg liter^{-1} and 2.3 mS when the fertilizer concentration was 250 mg liter^{-1}. With drip emitters the water waste was 29.3% over 7 irrigations. This was only leachate and the EC 3.2 mS when the fertilizer concentration was 350 mg liter^{-1} and 1.9 mS when the fertilizer concentration was 250 mg liter^{-1}. For the poinsettias the estimated daily water use was similar for all treatments and averaged 75 ml per pot per day and ranged from 33 ml

to 171 ml per pot per day over the course of the experiment.

There was no significant difference in cyathia retention and foliage quality between plants grown with different irrigation methods after 35 days in a simulated post harvest environment.

Easter Lily. There was no significant difference in plant height, number of flower buds, root quality nor in shoot fresh weight, and shoot dry weight between plants grown with different irrigation methods. The EC, and the N, K and Mg content of the biweekly root media samples averaged over the course of the experiment was significantly higher in the topwatering treatments (Table 1). There was not, however, any significant difference in the leaf tissue content (Table 3).

There was an average fertilizer solution waste of 42% for the drip emitters, calculated over 13 irrigations. The average EC of the drip tube leachate was 1.8 mS. The estimated daily water use for the Easter lilies was 60 ml per pot per day for the subirrigated treatments and 72 ml per pot per day for the drip emitters. Daily water use ranged from 35 to 101 ml per pot per day.

There was no significant difference in flower keeping quality between treatments after 19 days in a simulated post harvest environment. While the subirrigated poinsettias and Easter lilies (data not shown) had a higher level of soluble salts and nutrients in the upper third of root media, topwatering of these plants in a simulated post harvest environment did not reduce the keeping quality of the plants as compared to plants grown with topwatering methods.

Though there was no significant difference in the root media analysis for the poinsettias, there was a significant, though small,

difference in the leaf tissue content of P, Mo and Ca. All values were in a range suitable for plant growth, and did not have a significant effect on plant growth or quality. While there were significant differences in the root media analysis for the Easter lilies, there was no significant difference in leaf tissue nutrient content. Thus while the root media content was lower, none of the essential plant nutrients were limiting in plants subirrigated with half the fertilizer rate used for the topwatered plants.

While water use will vary with location, crop and weather, it is important to estimate the amount of water needed to grow a crop. Estimates of water use are useful in scheduling irrigations based on plant demand rather than time elapsed. Observations of grower leaching practices indicate areas of waste which are major contributions to runoff. Limiting leaching should be a major priority for the greenhouse industry. With subirrigation systems and recirculated nutrient solutions there is no runoff. Some changes in cultural practices, such as using lower fertilizer concentrations due to the absence of leaching, will be required with these systems. Subirrigated plants were comparable to topwatered plants in growth and development, with application of a lower concentration of nutrients and no production of effluent.

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Table 1. Poinsettia and Easter lily. Nutrient content of subirrigated and topwatered root media as measured by saturated paste extract.

Irrigation Method	EC (mS)	pH	N (mg liter^{-1})	P (mg liter^{-1})	K (mg liter^{-1})	Ca (mg liter^{-1})	Mg (mg liter^{-1})
			Poinsettia[W]				
Topwatered[X]	1.9	6.3	380	7	208	256	87
Subirrigated	2.4	6.3	516	8	247	349	107
	NS[Y]	NS	NS	NS	NS	NS	NS
			Easter lily				
Drip emitters	1.4	6.0	138	27	112	108	73
Subirrigated	1.0	6.1	83	11	79	91	56
	*	NS	**	NS	**	NS	*

[W]Average of six samples taken at two week intervals analyzed with time treated as a random effect in the analysis of variance.

[X]Topwatered is a combined sample from hand watering and drip emitters.

[Y]Average of seven samples taken at two week intervals analyzed with time treated as a random effect in the analysis of variance. NS, *, **: Analysis of variance F test not significant, significant at P=0.05, significant at P=0.01, respectively.

Table 2. Poinsettia. Distribution of soluble salts in subirrigated root media as measured by saturated paste extract.

Sample Position	EC (mS)	pH	(mg liter^{-1}) N	P	K	Ca	Mg
			Hand Watered				
Top[x]	2.57[y]	6.3	282	37	261	300	125
Middle	1.64	6.9	213	20	261	225	90
Bottom	1.64	6.8	208	18	239	210	81
			Drip Emitters				
Top	3.88[y]	6.2	558	19	322	495	203
Middle	1.39	6.8	124	10	141	135	62
Bottom	0.85	7.3	89	12	122	100	42
			Subirrigated				
Top	6.53[z]	6.3	878	22	480	780	475
Middle	1.34	6.7	147	46	183	120	62
Bottom	0.70	6.5	69	60	98	67	24
LSD (.05)	0.38	0.2	129	8	56	72	14

[x]Root media was partitioned into three equal sections approximately three cm tall.
[y] Value of a non-replicated single analysis of a sample which was a composite from three plants taken on 18 Dec.
[z]Mean of three samples taken on 18 Dec. Each sample was a composite from three plants.

Table 3. Poinsettia and Easter lily. Leaf tissue analysis of plants grown with topwatering or subirrigation.

	% Dry Weight					ug g^{-1} Dry Weight					
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
Irrigation Method					Poinsettia[X]						
Hand	4.1	0.42	2.89	1.21	0.71	85	58	40	2	51	1.2
Drip tubes	3.9	0.37	3.00	1.19	0.67	88	50	44	3	48	1.4
Subirrigation	4.0	0.39	2.77	1.06	0.64	74	50	49	2	50	1.4
Statistics[Y]											
LSD .05	NS	0.02	NS	0.07	NS	NS	NS	NS	NS	NS	0.06
.01	NS	0.03	NS	NS	NS	NS	NS	NS	NS	NS	0.09
					Easter lily[Z]						
Drip tubes	3.0	0.21	4.26	0.79	0.59	44	9	18	2	20	0.9
Subirrigation	3.1	0.37	4.63	1.22	0.60	51	15	26	3	27	0.9
Statistics	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[X]Average of three samples taken 18 December. A sample was five g fresh weight of newest green leaves.

[Y]NS, Analysis of variance F test not significant. LSD calculated at level of significance, P=.05 or P=.01.

[Z]Average of two samples taken 31 March. A sample was five g fresh weight of newest green leaves.

Section II Subject Category: HortScience Notes

Growth of Easter lily when irrigated with a bromine biocide in recycled subirrigation water.

Renee K. George, John A. Biernbaum, Royal D. Heins and Christine T. Stephens*

Department of Horticulture, Michigan State University, East Lansing, MI 48824

*Department of Botany and Plant Pathology, Michigan State University, East Lansing, MI 48824

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Continued growth in the use of irrigation systems with recirculated solutions for greenhouse container production is inevitable. The elimination of waste water containing fertilizer seems critical to the future of the greenhouse industry. Flood subirrigation with recycled solutions is an efficient method for irrigation, which has low labor requirements and no production of waste water. One of the major problems with recirculating solution production has been control of plant pathogenic organisms and algae (Tayama et al., 1986; Jenkins and Averre, 1983). A halogenated bromine compound (1-bromo-3-chloro-5, 5-dimethyl-2, 4-Imidazolidenedione, Agribrom™, Great Lakes Chemical Company, West Lafayette, IN) has been shown to control algae on subirrigation mats (Tayama et al., 1986) and is labelled for use as a biocide in greenhouse irrigation systems. The objectives of this research were to study the use of Agribrom™ for treatment of recirculated water with a flood subirrigation system and possible phytotoxicity on the growth of Easter lilies.

The Easter lilies used for the experiment were 'Nellie White', case cooled bulbs, 20.3-22.9 cm in circumference. Bulbs were potted in 15 cm standard (1500 cm^3 volume) on 17 Dec. 1987 in a soilless media (Baccto, Michigan Peat, Houston Texas) composed of peat, perlite and vermiculite with a starting pH of 5.6 and EC of 1.0 (Saturated Media Extract). Initially there were 90 plants per subirrigation bench at a spacing of 25 plants $meter^{-2}$.

The average date of shoot emergence was 1 Jan. 1988 and 80-90% of the shoots emerged in a 4 to 5 day period. Bulbs were topwatered after potting and drenched with 10 mg $liter^{-1}$ a.i. metalaxyl (Subdue, Ciba Geigy,

Greensboro, NC) and 60 mg liter^{-1} a.i. benomyl (Benlate, DuPont, Wilmington DE) on 15 Jan. 1988. A wetting agent, 1500 mg liter^{-1}, (Aqua-Gro, Aquatrols Corporation of America, Pennsauken, NJ) was applied on 18 Feb. 1988. Six subirrigation benches 1.2 meters wide and 3 meters long (Rough Brothers, Cincinnati, OH) each with an independent 200 liter reservoir were flooded at each irrigation with approximately 150 liters of nutrient solution for 15 to 20 minutes. The solutions were then drained back into the original reservoir and the reservoir was refilled to its original volume with fresh nutrient solution. The nutrient solution contained 100 mg liter^{-1} N and K and 40 mg liter^{-1} Ca from KNO_3, NH_4NO_3 and $Ca(NO_3)_2$. Phosphoric acid was also added to the nutrient solution as needed to maintain the pH of the solution in the range of 6.0-6.2.

There were three irrigation treatments consisting of 20-25 mg liter^{-1} free bromine (high rate), 5-6 mg liter^{-1} free bromine (label rate) and no Agribrom™ (control). Irrigation treatments were initiated on 22 Jan. 1988 and terminated on 31 March 1988 for a total of 69 days. The experimental design was a randomized complete block with three treatments and two replicates. The nutrient solutions were pumped onto the bench with a submersible pump (Little Giant Model NK-1). The Agribrom™ was injected through a Model 7gpm Dosatron (Dosatron International, Inc., Clearwater, FL) at a 1:100 dilution.

Agribrom™ stock solutions were prepared fresh at each irrigation. A near saturated solution was prepared from Agribrom™ granules, by heating to 40-50°C on a heated stir plate. This solution was then diluted to a concentration that would yield 20-25 mg liter^{-1} free bromine (high rate) after 1:100 dilution. A portion of this stock was then diluted 1:3

with water to yield a stock providing 5-6 mg liter^{-1} free bromine (label rate) after 1:100 dilution. The label recommendation is 5-10 mg liter^{-1}. Stock solutions were prepared in the laboratory and carried to the greenhouse in 2 liter containers. An average of 1.6 liters of stock solution was used for each irrigation.

Root media samples were taken biweekly. One set of samples was analyzed by the MSU Soil Testing Lab using the SME procedure and a second set was checked with a 1 part media and 2 parts water analysis. Plant tissue samples were collected biweekly. Plant height, number of flower buds, root evaluation and days to flower were recorded on 31 March 1988 for 72 plants from each replicate for a total of 144 values per treatment. Root evaluation was made on a visual rating scale of one to five. A rating of 1 was given to a healthy root system, 2 to a yellow root system with 25% of the roots necrotic, 3 to a root system with 50% of the roots necrotic, 3 to a root system with 75% of the roots necrotic and 5 to a root system with more than 75% of the roots necrotic. Free bromine was measured using a titration kit (DPD test kit, Great Lakes Chemical Corporation, West Lafayette, IN).

There was no significant effect of Agribrom^{TM} treatment on the pH and EC of the nutrient solution nor on final plant height, number of flower buds, days to flower and dry weight of plant samples taken at two week intervals during the crop. Root system evaluations were significantly better, 2.5 versus 2.9 (1 best and 5 worst), with the highest Agribrom^{TM} treatment. There was no significant difference between the root systems of the control and the label rate plants. With the high Agribrom rate a significant amount of leaf tip burn developed at the time of flowering.

At the termination of the experiment, twelve of the plants from each treatment were placed in a simulated postharvest environment at 22°C with 0.7 micro mols m^{-2} from cool white fluorescent lights for 24 hours per day. All plants were topwatered. Plants were evaluated after 19 days in this environment. There were no treatment effects on flower development in this environment. The further development of leaf tip burn on plants from the high treatment in the postharvest environment was significant and resulted in a poorer rating for these plants (2.75 for high vs. 1.83 for control, scale 1=best, 5=worst). After 19 days in the post harvest environment all of the plants from the high bromine treatment displayed leaf tip burn.

There were no differences in the results of root media analysis done at two week intervals. There was no significant difference in foliar nutrient levels, which is consistent with research conducted on chrysanthemum (Tayama and Carver, 1989). However, the level of Na in the plant tissue was significantly higher in the Agribrom™ treatments for the last two weeks of the experiment. Tissue and media levels of bromine and chlorine were not determined.

The average actual tested free bromine concentration over the course of the experiment as the nutrient solution entered the benches was 7 and 20 mg $liter^{-1}$ bromine for the two treatments. A sample of the nutrient solution and Agribrom™ mixture was also drawn from the far end of the bench after the bench was full. The average concentration of free bromine over the course of the experiment on the bench was 3 mg $liter^{-1}$ bromine for the low treatment and 5 mg $liter^{-1}$ bromine for the high treatment.

The final concentration of the label and high treatments was very similar considering the initial concentrations were almost 3 fold different. The concentration on the bench was influenced by the ambient level of sunlight and whether the sample was taken from the edge or the interior of the bench. Samples in full sunlight (approximately 600 μmols m^{-2} s^{-1}) had lower levels of free bromine. To test the effect of light on bromine level, we flooded the benches after dark for one irrigation. The bromine levels on the bench was 24 mg $liter^{-1}$ for the high rate when irrigated in the dark, compared to 7 mg $liter^{-1}$ when irrigated in the daylight.

The residual free bromine level in the reservoir one hour after irrigation averaged 3 mg $liter^{-1}$ bromine for the high treatment and 2 mg $liter^{-1}$ bromine for the low treatment. The residual activity in the barrels after 24 hours was less than one mg liter-1 for the label rate, and 1-2 mg $liter^{-1}$ for the high rate. Since the presence of organic matter on a bench will significantly reduce the oxidizing activity of the Agribrom™ treated nutrient solution, and the residual activity od the bromine, it is important to note that there was little or no root media or other organic media on the bench surface during this test.

It was not possible to draw conclusions about the beneficial effects of Agribrom™ on limiting fungi, bacteria and algae in the nutrient solution in this study because there were no major algae or pathogen problems in the control plants. The beneficial effects of Agribrom™ could best be evaluated in a system where the fungal pathogen or the algae is artificially introduced. With regard to subirrigation systems, an important variable is the minimization of root media on the benches.

Another concern that could be addressed in totally closed subirrigation systems is whether Agribrom™ needs to be injected at every flooding or at some regular interval.

This study has provided some basic knowledge about the use of Agribrom™ in recirculated nutrient solution systems for the production of greenhouse container plants in a peat based media. The primary conclusions were that there were no phytotoxic effects on Easter lilies when Agribrom™ was injected at the label rate (5 to 6 mg liter^{-1} free bromine) at each irrigation during almost the entire production period. However there was no significant difference between the root evaluation results between the control plants and those grown with the label rate of Agribrom™. The root evaluation results from those plants grown with the high (20-25 mg liter^{-1}) of Agribrom™ were significantly better than the controls, but approximately 10 to 15% of the plants from the high Agribrom treatments were not marketable at the end of the experiment. Twelve plants grown in production with the high rate of Agribrom™ were grown for 19 days in a post harvest environment. All 12 were not marketable at the end of the post harvest treatment because of tip burn. Higher leaf tissues of Na could have been associated with or contributed to the leaf tip burn. The leaf tip burn may have also been associated with chlorine or bromine in the tissue or media, as lilies are sensitive to fluoride (Marousky and Woltz, 1977).

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Section III

Spread of *Pythium ultimum* and *P. aphanidermatum* in production of seedling geraniums with subirrigation versus topwatering with recycled solutions.

Renee K. George, John A. Biernbaum, Christine T. Stephens*, Royal D. Heins

Department of Horticulture, Michigan State University, East Lansing, MI 48824

Department of Botany and Plant Pathology, Michigan State University, East Lansing, MI 48824

Acknowledgement is made to the Michigan Agricultural Experiment Station, and the American Floral Endowment for their support of this research. Cultures were provided by Dr. A. F. Schmitthenner, Columbus, Ohio.

Abstract. **Geranium (*Pelargonium X hortorum* L.H. Bailey 'Ringo Scarlet') seedlings were grown with subirrigation (sub) or topwatering (top) with recycled solutions. Irrigation trays contained 3 non-inoculated plants and either a control plant or a plant inoculated with *Pythium ultimum*. Pythium ultimum was detected in recycled water in 3 of 4 topwatered and 2 of 4 subirrigated trays. Plants became diseased in 1 of 4 topwatered and 1 of 4 subirrigated trays.**

In a separate experiment with *Pythium aphanidermatum*, topwatered or subirrigated trays contained non-inoculated geraniums in either Baccto Professional Growers Mix, Baccto drenched with metalaxyl or Naturally Suppressive Ball Growing Mix 2 and either a control plant or an inoculated plant. *Pythium aphanidermatum* was detected in recycled water in 4 of6 topwatered and 3 of 6 subirrigated trays. Plants became diseased in 3 of 6 topwatered and 3 of 6 subirrigated trays. Spread of *Pythium aphanidermatum* occurred into plants in all three media. Similar results were observed in a repeat of this experiment.

The awareness of groundwater contamination issues and the need for more labor efficient methods of watering greenhouse crops have created interest in flood subirrigation in recent years. Systems which recirculate waste water containing fertilizer are critical to the future of the greenhouse industry. While there has been research in disease spread through the recirculating solution of hydroponics, no research to date has been published in the United States on plant to plant disease spread in a container production system with recirculated nutrient solutions.

There have been reports of *Pythium sp.* spreading through the

recirculated solutions of hydroponic and nutrient film technique (NFT) systems (Bates and Stanghellini, 1984, Daughtery and Schippers, 1980, Evans, 1979, Jenkins and Averre, 1983, Stanghellini and Russell, 1971, Stanghellini et al., 1984). Plant losses as high as 100% from *Pythium aphanidermatum* Edson (Fitzp.) were shown on hydroponically grown spinach (Stanghellini et al., 1984) and tomato seedlings (Stanghellini and Russell, 1971) under research conditions. *Pythium ultimum* caused 100% disease in hydroponically grown cucumbers and tomatoes 22 days after introduction of the inoculum into the system (Jenkins and Averre, 1983). *P. ultimum* also caused 100 % death in cucumbers 10 weeks after inoculation of the water in an NFT system (Evans, 1979). In contrast, little spread of pathogens in NFT culture has been found by other researchers (Staunton and Cormican, 1978 and 1980).

It is not clear what effect the organic peat based media used in container plant production has on the spread of pathogens in a recirculated solution. Hockenhull and Funk-Jensen (1983) suggested that pathogen spread would be less in a hydroponic system with exposed roots than in container culture with organic media because the constant flow of the nutrient solution would sweep root exudates and zoospores away from the root zone. Alternately it has been hypothesized that pathogen spread would be less when plants are protected by pots and peat medium (Staunton and Cormican, 1978). Kiplinger et al. (1975) suggested that diseases were not a problem with subirrigation because water can only move up in the capillary pores, which leaves sufficient oxygen in the non-capillary pores to discourage disease development.

To determine the degree of pathogen spread in a flood subirrigation

system with recirculated nutrient solutions, geranium plants growing in media inoculated with either *Pythium ultimum* or *Pythium aphanidermatum* were grown with disease free plants. Pathogen spread and the impact of the pathogen on plant growth were evaluated.

As an additional bio-indicator, geraniums were sprayed with silver thiosulfate (STS). STS application to seed-propagated geraniums infected with even a low level of *Pythium* can result in premature plant death caused by lower stem blight (Hausbeck, et al. 1988). Application of STS to *Pelargonium X hortorum* L.H. Bailey 'Ringo Scarlet' plants increased the percent of plant death to 62 to 100% compared to 0 to 38% without STS.

Experiment 1. Twenty day old geranium seedlings were transplanted into round plastic pots 9 cm in diameter and 8.5 cm tall with four one cm holes on the bottom of the pot. Each pot contained 250 cm3 of either *Pythium ultimum* inoculated media (I) or non-inoculated media (NI). A commercially available peat based medium (Baccto Professional Growers Mix, Michigan Peat, Houston, TX) composed of peat, perlite, and vermiculite with a starting pH of and 5.6 and EC of 1.0 mS (Saturated Media Extract) was used for all treatments. A pathogenic isolate of *Pythium ultimum* Trow, known to cause root rot, lower stem rot, plant stunting and delay in flowering in geranium (Hausbeck, et al.,1988) was used to produce the inoculum using the potato medium procedure developed by Ko and Hora (1971). Fifty grams of finely chopped potato was added to 500 ml of the peat based medium and autoclaved twice, for one hour, 24 hours apart. Cultures of *P. ultimum* were maintained on 20 ml of water agar (Difco Laboratories, Detroit, MI) and grown in 10 cm plates for two days at 21°C. Two mycelial disks 12 mm in diameter were selected from the edge of the

culture and used to inoculate 500 ml of the sterilized potato medium. The inoculum was grown in 1.0 liter closed flasks for two weeks and shaken daily. The inoculum was air dried for two days and sieved through a 3 mm screen. The rate of inoculum used was 3.0 g of inoculated media $liter^{-1}$ of fresh media.

Plants were grown in a 20°C greenhouse for ten days before treatments began. All plants received 200 mg liter-1 N and K from $Ca(NO_3)_2$ and KNO_3 four days after transplant. One foliar application of 750 mg liter-1 chlormequat (Cycocel, American Cyanamid, Wayne, NJ) was made 15 days after transplant. Three NI and one I plant were placed in each of eight trays, 22 cm in diameter, 6 cm high. Eight trays with four NI plants in each served as controls. Half the trays were subirrigated and half were topwatered. For the subirrigated treatments the trays were each connected by tubing to a four liter opaque reservoir containing fertilizer solution. Plants were irrigated as needed by filling the tray with approximately 400 ml of solution (2 cm deep). The solution was in the trays for a total of seven minutes, including the time to fill and drain. For the topwatering treatments the trays were not connected to the reservoirs and were watered from the top. A 1 cm tall waffled riser was placed in the topwatered trays to allow the leachate to drain away from the plants into a container. A small funnel, one per tray, was used to direct water into the pot. Plants were irrigated to a 20% leaching fraction and the leachate was returned to the reservoir. Approximately 100 ml were applied per plant, approximately 75 ml total leachate was recycled at each irrigation. All plants in all treatments were kept from contacting each other by transparent plastic sheets between plants.

Treatments were initiated on 15 July, 1989 with an initial fertilizer concentration of 50 mg liter^{-1} N and K from $Ca(NO_3)_2$ and KNO_3 EC of 1.05 mS). The fertilizer used to replenish the reservoirs as needed was increased to 75 mg liter^{-1} N and K from $Ca(NO_3)_2$ and KNO_3 (EC of 1.18) on 11 Aug 1989. All plants received a subirrigated application of 630 mg liter^{-1} S.T.E.M. (Soluble Trace Element Mix, Peters, Fogelsville, PA) and 0.32 ml liter^{-1} 85% H_3PO_4 on 5 Sept. 1989. This solution had a pH of 4.5 and an EC of 0.87. During the course of the experiment the NI plants had a pH in the range of 6.3 - 7.3 and an EC between 0.28 and 0.86 mS (2 water:1 media). The treatment arrangement was a randomized complete block with four treatments and four replicates per treatment. Plants were grown in a 20°C glass greenhouse with a shade curtain. Supplemental lighting from high pressure sodium lights providing a PPF of 130 μmols m^{-2} s^{-1} for 18 hours per day were used from 2 Aug. 1989 to 4 Sept. 1989. This lighting arrangement was implemented to help maintain day temperatures $\pm$2°C in the greenhouse.

A 0.25mM application of STS (Heins et al.,1984) was applied on 6 Sept. Eight weeks after the initiation of irrigation treatments pathogen presence was determined and plant growth was evaluated by measuring plant dry weight. Roots were washed in running tap water to remove the potting medium. Root sections, residue filtered from the solution reservoirs, and media samples were plated on antibiotic selective agar, (10 mg Pimaricin, 200 mg Ampicillin, 50 mg PCNB, 10 mg Rifampcin and 17 g corn meal agar per liter, 20 ml per 10 cm Petri dish). For each plant, two root sections 3 cm long were washed for 10 minutes in running tap water. Approximately 0.4 g of root medium taken from the perimeter of the root ball 2 cm from

the bottom of the pot was used as a sample. Water residue, 0.1 ml per plate, was filtered from the reservoirs with a #325 mesh screen which was surface sterilized with a 0.5% sodium hypochlorite solution and rinsed with sterile distilled water between each use. Plates were incubated at 15°C.

Root medium and stem tissue from the NI plants in I trays and residue filtered from the solution reservoirs were further tested for *P. ultimum* with an ELISA kit (Agri-Diagnostics, Cinnamonson,NJ). A sample consisted of 0.4 g of fresh stem tissue, or 0.4 g of medium, (sample taken as described for plating). All of the residue obtained from the water constituted a sample.

Experiment 2. Twenty eight day old geranium seedlings were transplanted into round standard pots 9 cm in diameter containing Baccto media (NI), Baccto media drenched with 100 ml of 10 mg liter^{-1} a.i. metalaxyl (NIM) or into Naturally Suppressive Ball Growing Mix 2 (Ball Seed, West Chicago, IL) (NIS) and were grown for ten days before treatments began as in Expt 1.

Twelve plants in Baccto media were inoculated with *Pythium aphanidermatum* Edson (Fitzp.). To prepare inoculum pure cultures of *Pythium aphanidermatum* #246, known to be pathogenic on geranium, (A.F. Schmitthenner, personal communication), were grown on 20 ml of V-8 agar in 10 cm Petri plates for four days at 26°C. After four days, plates were cut into 25 pieces and were added to one liter of sterile tap water. One plate was used per liter. The water was kept in a flask wrapped in foil at 26°C for 24 hours, to allow zoospore development. The agar was filtered from the water with sterile cheesecloth after 24 hours. Each plant to be

inoculated (I) was placed in a tray and watered with 140 ml of the water containing zoospores. Approximately 25 ml of the water leached into the trays. Plants in the trays were incubated at 26°C for 24 hours before being moved to the greenhouse. Twelve plants planted in Baccto media which were watered with sterile tap water in the same manner served as controls, (C).

Three non-inoculated plants in selected media and one inoculated plant or one healthy plant were placed in each irrigation tray. One half of the trays were subirrigated and one half were topwatered as in Expt. 1.

Treatments were initiated on 21 July, 1989 with the same fertilization treatment as in Expt. 1. The NI plants had a pH in the range of 6.3 - 7.5 and an EC between 0.34 and 1.08 mS (2 water:1 media) during the course of the experiment. There were twelve treatments and two replicates per treatment. Plants were grown in a greenhouse under ambient light with a shade curtain pulled when PPFD exceeded 1000 μmol m^{-2} s^{-1}. The day temperature set point was 27°C and the night temperature set point was 24°C. Temperatures were maintained $\pm$ 2°C. A 0.25mM STS application was applied on 30 Aug. and again on 8 Sept. 1989. Plant growth was evaluated and pathogen presence determined after eight weeks with the same procedure as Expt. 1 except plates were incubated at 26°C.

Experiment 3. Experimental set up and execution was the same as Expt. 2 except 21 day old geranium seedlings were used. Thermostatically controlled electrical resistance heating mats were placed beneath the reservoirs to maintain the temperature of the fertilizer solution at 27oC. Irrigation treatments were initiated on 13 August with an initial fertilizer concentration of 75 mg $liter^{-1}$ N and K from $Ca(NO_3)_2$ and KNO_3

(EC of 1.18). The fertilizer used to replenish the reservoirs was increased to 100 mg liter^{-1} N and K from $Ca(NO_3)_2$ and KNO_3 and 0.26 ml liter^{-1} 85% H_3PO_4 (EC of 1.26). During the course of the experiment the NI plants had a pH in the range of 6.2 - 7.1 and an EC between 0.15 and 1.19 mS (2 water:1 media). A 0.25mM STS application was applied on 8 Sept. and 16 Sept., 1989. Plant growth was evaluated and pathogen presence determined seven weeks after treatments began with the same procedure used in Expt. 2.

A randomized complete block treatment arrangement was used for Expt. 2,3, and 4. Root media analysis was done at the termination of all experiments at the MSU Soil Testing Laboratory (East Lansing, MI). Analysis of variance was performed on all data with BMDP 2V PC software.

Experiment 1. *P. ultimum* was isolated from the roots of one symptomless control plant at harvest. *P. ultimum* was isolated from all inoculated plants and media on selective agar. Four of the eight inoculated plants died and severe stunting occurred in the remaining four within two weeks after irrigation treatments began. After spraying with STS, one of the four stunted inoculated plants developed stem rot.

P. ultimum was isolated from NI plants in trays containing an inoculated plant in two of the topwatered (2 of 3 plants, 1 of 3 plants) and one of the subirrigated treatments (3 of 3 plants), indicating plant to plant spread via the water. *P. ultimum* was isolated from the recycled water but disease did not occur in healthy plants in two of the topwatered and one of the subirrigated treatments.

The average dry weight of the subirrigated NI plants which were in trays with inoculated plants was significantly lower than the average dry

weight of the topwatered NI plants which were in trays with inoculated plants and significantly lower than the NI plants in the topwatered control trays.

Experiment 2. No *P. aphanidermatum* was isolated from trays containing only healthy plants. *P. aphanidermatum* was isolated from all inoculated plants and root media on selective agar. Plant mortality in seven of the twelve inoculated plants and stunting in the remaining five within two weeks after irrigation treatments began. One inoculated plant developed stem rot four weeks after treatments began and three of the remaining four developed stem rot after spraying with STS.

There was no significant difference in dry weight between plants grown in the different media or between subirrigated and topwatered plants. There was a significant difference in the average dry weight of the non-inoculated plants in trays which contained an inoculated plant and the non-inoculated plants in trays which contained only healthy plants, 3.98 g per plant and 5.91 g per plant respectively. This difference was due to disease spread in the trays which contained an inoculated plant. Pathogen isolation data from the non-inoculated plants is shown in Tables 1 and 2. *Pythium aphanidermatum* was detected in recycled water in 1 topwatered tray and plants became diseased in 3 of 6 topwatered and 3 of 6 subirrigated trays. Spread occurred into plants in all three media.

Experiment 3. P. aphanidermatum was isolated from all inoculated plants and root media on selective agar. Mortality occurred in six of the twelve inoculated plants and stunting in the remaining six within two weeks after irrigation treatments were initiated. Five of the six stunted inoculated plants developed stem rot after being sprayed with STS.

Pythium aphanidermatum was detected in recycled water in 3 topwatered trays and in one subirrigated tray. Plants became diseased in 2 of 6 topwatered and 4 of 6 subirrigated trays. Spread of *P. aphanidermatum* occurred in two trays which contained non-inoculated plants potted in Baccto, one tray with non-inoculated plants potted in Baccto drenched with metalaxyl and in three trays with non-inoculated plants potted in Ball 2.

Media nutrient levels were not significantly different in the different treatments for any of the experiments (Data not shown).

There are many factors which can influence the degree of spread of organisms in subirrigation systems when the water is recirculated or in hydroponic systems. It has been suggested that the variability of results found by different researchers in NFT and hydroponic studies have been due to different inoculum or inoculation techniques (Staunton and Cormican, 1980), variation in the temperature of the nutrient solution (Bates and Stanghellini, 1984), different initial populations of fungal flora in the systems (Price, 1980), and the absence of predisposing factors, such as water stress (Daughtrey and Schippers, 1980).

Salinity and fertility levels can also influence disease incidence. Rasmussen and Stanghellini (1988) found an increase in disease incidence of cottony blight caused by *Pythium aphanidermatum* of creeping bentgrass as salinity was increased. Gladstone and Moorman (1987) reported an increase in mortality of seedling geraniums from root rot caused by *Pythium ultimum* as levels of nitrogen and phosphorus fertilization were increased.

The plants in Expt. 1 were grown at a temperature which favored the

pathogenicity of *Pythium ultimum* (Alexander, et al., 1932). The optimum temperature for infection by *Pythium aphanidermatum* is 35-40°C (Plaats-Niterink, A. J. Van Der, 1981). Plants in Expts. 2 and 3 were grown at 25 - 30°C which is the optimum temperature for the zoospores production in *Pythium aphanidermatum* and is a temperature more suitable for geranium growth (Carlson and Hilliard, 1986). Less infection occurred from water reservoirs containing zoospores in Expt. 3 than in Expt. 2 possibly due to lower daily temperatures in Expt. 3. Plants in Expts. 1 and 2 had symptoms of nutritional stress, which may have contributed to higher levels of infection. All but one of the infected plants in Expt. 2 had visible stem rot at harvest, whereas over half of those plants in Expt. 3 which were infected did not have visible symptoms.

An interaction between STS application and the expression of stem rot, as was previously reported for *Pythium ultimum* (Hausbeck et al., 1988) also occurred with *Pythium aphanidermatum,* with 5 of 6 stunted inoculated plants developing stem rot after STS application in Expt. 3. The ELISA was as effective as plating in detecting *P. aphanidermatum* in infested media. However, the ELISA was not as effective as plating in detecting *P. ultimum* in infested media presumably due to the poorer distribution of *P. ultimum* propagules in the soil. The ELISA was less effective than plating for isolation from water. Use of plating or the ELISA on fruit or leaves used to trap the organism may be more effective (Klotz, et al., 1959; Thomsom and Allen, 1974).

In Experiments 2 and 3 there was no difference in the amount of disease spread between the topwatered and subirrigated treatments combined over media nor between the media types combined over irrigation type based on

a normal binomial distribution. Neither the naturally suppressive Ball 2 media nor a single drench of metalaxyl protected plants from *P. aphanidermatum* for eight weeks.

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Table 1. Spread of *Pythium aphanidermatum* from an inoculated plant to non-inoculated plants with topwatering or subirrigation in Expt. 2.

	Topwatered	Subirrigated
Trays with plant to water spread[xy]	4	3
Trays with plant to plant spread[xy]	3	3

[x] Number of trays added over 3 media types. Total number of trays per irrigation method was six.

[y] Not significantly different based on a normal binomial distribution.

Table 2. Comparison of spread of *Pythium aphanidermatum* from an inoculated plant to non-inoculated plants in different root media in Expt. 2.

	Baccto	Baccto w/Metalaxyl	Ball 2 Suppressive
Trays with plant to water spread[xy]	4	1	2
Trays with plant to plant spread[xy]	3	1	2

[x] Number of trays added over two irrigation methods. Total number of trays per media type was 4.

[y] Not significantly different based on a normal binomial distribution.