Root Rot of Hydroponically Grown Spinach Caused by *Pythium aphanidermatum* and *P. dissotocum*

M. L. BATES, Research Associate, Environmental Research Laboratory, and M. E. STANGHELLINI, Professor, Department of Plant Pathology, University of Arizona, Tucson 85721

ABSTRACT

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Root rot was the limiting factor to commercial production of spinach (*Spinacia oleracea*) in a greenhouse recirculating hydroponic system in Arizona. Infected plants either died or were severely stunted. Two species of *Pythium* (*P. aphanidermatum* and *P. dissotocum*) were associated with root rot. *P. aphanidermatum* predominated as the primary causal agent of root rot during the warm summer production months, when nutrient solution temperatures were higher than 23 C, whereas *P. dissotocum* was the primary or sole causal agent during the winter production months, when nutrient solution temperatures were between 17 and 22 C. Disease symptoms, identical to those observed in the commercial greenhouse, occurred within 6 days after spinach plants were inoculated with either *P. aphanidermatum* or *P. dissotocum*. It was also shown that metalaxyl, at concentrations from 1 to 10 μg a.i./ml in the nutrient solution, was effective in controlling root rot of spinach.

In cooperation with Kraft Foods, Inc., the Environmental Research Laboratory of the University of Arizona designed and operated a prototype commercial production facility for hydroponic culture of lettuce and spinach. Production continued year-round in a 0.5-ha greenhouse containing 10 raceways, each 4 m wide, 70 m long, and 30 cm deep (Fig. 1A). Each raceway contained 76,000 L of a recirculated, aerated nutrient solution. Four commercial cultivars of leaf lettuce (*Lactuca sativa* L.) and one of spinach (*Spinacia oleracea* L. 'Melody') were transplanted as 2-wk-old seedlings into 3-cm-diameter holes, spaced 17 cm apart, cut in plastic flotation boards 1.2 × 2.5 × 2.5 cm. From transplanting to harvest was 4–6 wk. As boards of plants were harvested from one end of the raceway, new boards were introduced to the other end.

Production of lettuce and spinach crops began in September 1981. In October, damping-off of spinach seedlings was observed within 1 wk of transplanting (Fig. 1B). Infected plants showed extensive root rot, wilt, severe stunting, and death. Lettuce plants growing in the same raceways with infected spinach plants apparently were not affected. *Pythium aphanidermatum* (Edson) Fitzp. was consistently isolated from rotted roots of dead and dying spinach plants. The temperature of the nutrient solution in the raceways at this time was 26 C. Because the temperature of the nutrient solution would decrease with the onset of the winter, it was felt that *P. aphanidermatum*, a recognized high-temperature root pathogen, would not be a continuing problem. Although the temperatures of the nutrient solution did decline in November to 22 C, stunting and seedling death continued. Isolations from roots of stunted and dead plants in November revealed, however, that a second species of *Pythium*, *P. dissotocum* Drechs., was now the predominant species associated with diseased plants. Production of spinach as a commercial crop was subsequently abandoned.

Pathogenicity of *P. aphanidermatum* and *P. dissotocum*, the cyclic occurrence of these two species, incidence of disease in a naturally infested commercial raceway, and chemical control studies are presented in this paper. A preliminary report has been published (1).

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MATERIALS AND METHODS

Pathogenicity tests. Pathogenicity tests were conducted in the commercial greenhouse under hydroponic conditions. Eight 2-wk-old spinach seedlings were transplanted into holes cut into Styrofoam flotation boards (42 × 35 × 2.5 cm). Planted boards were then placed in each of eighteen 30-L plastic tanks filled with a continuously aerated nutrient solution (Fig. 2). The temperature of the nutrient solution was adjusted to either 20 or 30 C with 75W submersible aquarium heaters. Each tank was infested with a 48-hr-old V-8 agar culture of either *P. aphanidermatum* or *P. dissotocum*. Uninfested tanks served as controls. All studies were replicated twice and repeated once. Disease severity was evaluated daily over a 4-wk period. Additionally, three to five root segments (each 4 cm long) were collected from each plant in each tank, rinsed in running tap water for 10 min, and plated on 2% water agar. After 48 hr of incubation at 24 C, isolated fungi were identified.

Disease incidence. To determine the seasonal occurrence and incidence of root rot of spinach caused by *P. aphanidermatum* and *P. dissotocum*, one flotation board containing 100 spinach seedlings (2 wk old) was placed daily during a 1-yr period in a naturally infested commercial raceway. The percentage of plants showing stunt or death per board was recorded weekly during a 4-wk period. Roots of 10 stunted or dead plants were collected per flotation board 2 wk after placement in the raceway and prepared for isolation as described before. Data were recorded on the frequency of isolation of *P. aphanidermatum* and *P. dissotocum*. The temperature of the raceway nutrient solution was recorded daily throughout the year on a recording thermograph.

Chemical control trials. Chemical control trials were conducted in the 30-L tanks described previously. Treatments included addition of various concentrations of metalaxyl (Ridomil 2E), zineb 75W, captan 50W, or chlorine (from NaOCl) to tanks filled with either the nutrient solution from a *P. aphanidermatum*- and *P. dissotocum*-infested raceway or an uninfested nutrient solution. Nonchemically amended tanks served as controls. All tanks were planted as described previously and data collected regarding disease control during a 14-day incubation period at 23 C.

RESULTS

Pathogenicity tests. Disease symptoms identical to those observed in a naturally infested raceway occurred within 6 days after spinach plants were inoculated with either *P. aphanidermatum* or *P. dissotocum*. Isolations from roots of inoculated and diseased plants consistently yielded the respective species of *Pythium* used as inoculum. Both species were pathogenic at 20 and 30 C but *P.*

aphanidermatum was more virulent at 30 C (Table 1).

Disease incidence. Incidence of root rot of spinach caused by *P. aphanidermatum* and *P. dissotocum*, a disease that occurred continuously over the 1-yr test period, was related to the temperature of the nutrient solution (Fig. 3). The lowest disease incidence (<25% of plants stunted or dead) occurred in January and February, when the nutrient solution temperatures were lower than 20 C. Highest disease incidence (>50% of the plants stunted or dead) occurred throughout the remainder of the year, when the nutrient solution temperatures exceeded 20 C. The causal agent(s) of root rot in a particular month varied, however, depending on the temperature of the nutrient solution. *P. dissotocum* was the predominant or sole pathogen at temperatures lower than 23 C, whereas *P. aphanidermatum* was the predominant or sole pathogen at temperatures higher than 23 C. Both pathogens were seldom isolated from the same diseased root or plant.

Chemical control. Metalaxyl, at concentrations of 1, 2, 5, and 10 μg a.i./ml in the nutrient solution, was effective in preventing root rot of spinach but was slightly phytotoxic at 10 μg a.i./ml. Chlorine, at concentrations of 1, 3, 6, and 10 μg/ml, and zineb or captan, at concentrations of 2, 10, 25, 50, 100, and 200 μg a.i./ml in the nutrient solution, either failed to control root rot or were extremely phytotoxic.

DISCUSSION

Production of vegetable crops in greenhouses employing a recirculating hydroponic cultural system has been used worldwide for many years. One of the proposed advantages of such a cultural system has been avoidance of diseases caused by root pathogens (2,7,10). In general, few destructive root diseases have been reported, but where they have occurred (3,6,8), cultivation of the susceptible crop has been either temporarily or permanently abandoned. The devastating effects of a root pathogen once introduced into such a cultural

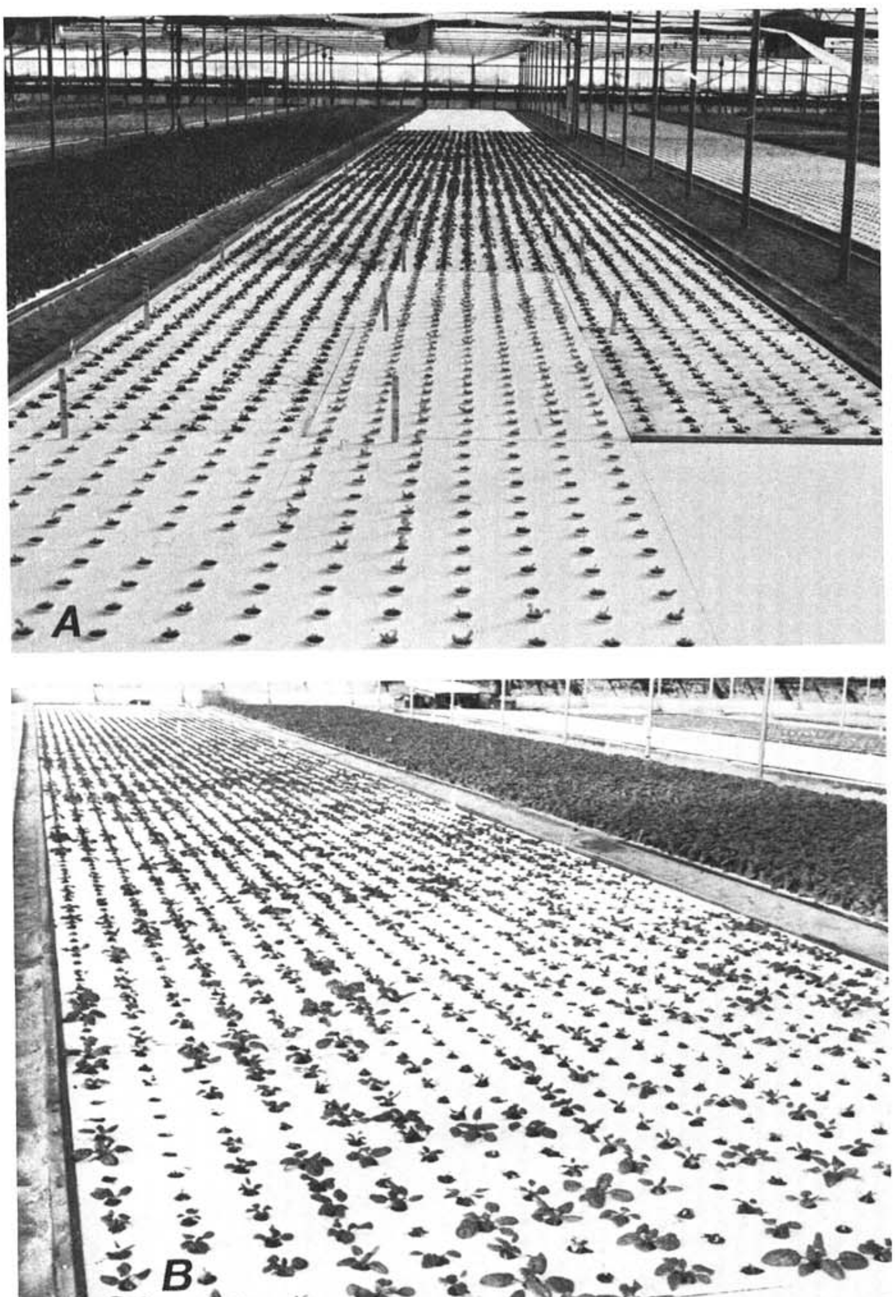

Fig. 1. Commercial production of spinach in a recirculating hydroponic system. **(A)** Healthy spinach plants. **(B)** Stunting and death of spinach plants caused by *Pythium aphanidermatum* and *P. dissotocum*.

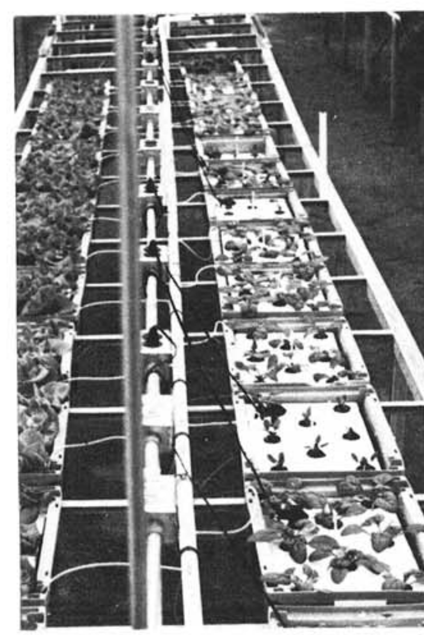

Fig. 2. Hydroponic system used for pathogenicity and chemical control studies of *Pythium aphanidermatum* and *P. dissotocum* on spinach.

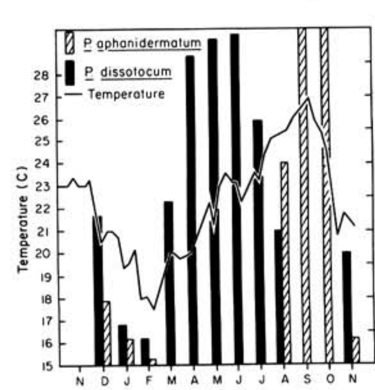

Fig. 3. Effect of nutrient solution temperature on the incidence of root rot of spinach caused by *Pythium aphanidermatum* and *P. dissotocum* in a commercial recirculating hydroponic system.

Table 1. Pathogenicity of *Pythium aphanidermatum* and *P. dissotocum* on spinach grown hydroponically[a]

Treatment	Nutrient solution temperature (C) 20: Plants stunted (%)	20: Plants killed (%)	30: Plants stunted (%)	30: Plants killed (%)
P. aphanidermatum	100[b]	0	0	100[c]
P. dissotocum	69[b]	0	100[d]	0
Control	0	0	0	0

[a] Sixteen plants per treatment; data collected 14 days after infestation of the nutrient solution.
[b] Symptom expression began 10 days after infestation.
[c] Symptom expression began 2 days after infestation.
[d] Symptom expression began 5 days after infestation.

system are illustrated in our report. Commercial production of spinach was abandoned within 3 mo of cultivation as a result of severe root rot caused by *P. aphanidermatum* and *P. dissotocum*. This is the first report of these two *Pythium* species as pathogens of spinach and the first report of *P. dissotocum* as a pathogen of any vegetable crop grown under hydroponic conditions. Drechsler (4) reported the isolation of *P. dissotocum* from discolored roots of field-grown spinach but he did not conduct pathogenicity tests. *P. aphanidermatum*, however, is a recognized pathogen of hydroponically cultivated tomatoes (5,6,8) and cucumbers (6) and has been isolated from necrotic roots of field-grown spinach (9).

The temperature of the nutrient solution influenced disease incidence and the cyclic occurrence of these two *Pythium* species as causal agents of root rot of spinach. *P. aphanidermatum* was the primary or sole pathogen at temperatures higher than 23 C, whereas *P. dissotocum* was the primary or sole pathogen at temperatures lower than 23 C. Disease incidence, regardless of the temperature of the nutrient solution (which ranged from 17 to 27 C) was above the threshold necessary for continued economic production of spinach; however, disease incidence was lowest at nutrient solution temperatures lower than 20 C. This observation may provide an explanation for the apparent absence of catastrophic root diseases in Europe, where solution temperatures are seldom higher than 20 C. In the United States, solution temperatures are seldom lower than 20 C and frequently approach 30 C. Thus, manipulation of the temperature of the nutrient solution, if coincident with minimum temperatures necessary for economic production of a particular vegetable crop, could be used as a cultural method for controlling certain root diseases.

Our studies showed that metalaxyl, at concentrations of 1–10 μg a.i./ml in the nutrient solution, was effective in controlling root rot of spinach; however, this chemical is not currently registered for use on greenhouse vegetable crops. Both captan and zineb, which are registered for use, were either phytotoxic at concentrations capable of suppressing the development of root rot or were ineffective at nonphytotoxic concentrations. Chlorine, although reportedly effective in controlling *P. aphanidermatum* root rot of cucumbers and tomatoes in recirculating hydroponic systems (5), was not effective in controlling root rot of spinach at concentrations ranging from 1 to 6 μg/ml and was extremely phytotoxic at 10 μg/ml.

The avenue of introduction of *P. aphanidermatum* and *P. dissotocum* into the recirculating system was not investigated thoroughly but neither species could be isolated from seedlings obtained from the nursery despite numerous attempts. The most likely source of contamination, however, was the river sand used in the walkways and support foundation for the commercial raceways. Both *P. aphanidermatum* and *P. dissotocum* are indigenous to Arizona and have been isolated from river sand (M. E. Stanghellini, *unpublished*).

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