

Effect of Location of Drip Irrigation Emitters and Position of *Phytophthora capsici* Infections in Roots on Phytophthora Root Rot of Pepper

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ABSTRACT

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The effects of the location of drip irrigation emitters and the position of inoculum in roots on Phytophthora root rot of pepper were studied on cultivars Yolo Wonder B (susceptible) and Adra (resistant). In field plots infested with *Phytophthora capsici*, the location of emitters had major effects on incidence of diseased plants, severity of root symptoms, yield, shoot dry weight, level of soil moisture, and plant leaf water potential. Disease levels were highest with emitters at the soil surface and in the plant row. The subsurface (15 cm deep) position gave the most efficient control in the field without reducing yields in noninfested plots. Disease

levels were more severe with cv. Yolo than with cv. Adra. Results were similar in analogous greenhouse tests. In complementary experiments, when zoospores were placed onto tips of roots that were 7 to 10 cm or 14 to 18 cm long, inoculation at different positions in the root system had no effect on the lesion growth rate for either cultivar, but the progress of lesions on 'Yolo' was three to five times faster than on 'Adra'. Moreover, the rate of lesion growth declined with time on 'Adra', but remained constant in 'Yolo', and above-ground symptoms of root rot on 'Yolo' were more severe when inoculum was placed higher in the soil profile. Phytophthora root rot of pepper can be reduced in low rainfall areas by positioning the drip emitters away from plant stems, with a subsurface location giving the best results. The advantages of associating genetic resistance with a well-managed drip system were evident.

Phytophthora capsici Leonian is an important pathogen of peppers (*Capsicum annuum* L.) (2,4,22), causing both an aerial blight and a root and crown rot. Under heavy rainfall or excessive sprinkler irrigation, the blight phase is the most important phase (24). On the other hand, little or no blight occurs in some semiarid areas such as the Central Valley of California, where rains are infrequent during the growing season and furrow or drip irrigation is used. Under these conditions, where the root and crown rot phase of the disease is important, reduction in frequency or intensity of furrow irrigation has been shown to reduce root rot of bell pepper (7), chili pepper (*Capsicum annuum*) (2), and squash (*Cucurbita pepo* L. var. *melopepo*) (8) caused by *P. capsici*. Moreover, in studies conducted under moderate rainfall conditions, lower frequency of drip irrigation resulted in less disease on pepper (22).

Increases in Phytophthora root rots with increased irrigation are attributed to greater pathogen activity and infection in saturated soil conditions (3,11,15). While soil moisture is certainly important, there have been no attempts to examine the effect of the location of the drip irrigation emitters on the development of root rots caused by *P. capsici*. The position where the soil is wetted, relative to the host roots, is likely to affect the development of the disease, because sporangium formation and the release and movement of zoospores to roots occur only in moist soil (1,9-11). In addition, the location of infection initiation on roots on each individual plant probably has a strong effect on the final disease severity. For example, lesions started near the stem are more likely to girdle the crown area than are lesions initiated on more

distal parts of the root system. This study investigated the effects of the placement of drip emitters and inoculum at various locations on the roots on the development of Phytophthora root rot in susceptible and partially resistant genotypes of bell pepper. A portion of this work has been published (6).

MATERIALS AND METHODS

Field experiments. A field experiment was conducted in Yolo loam soil at the plant pathology field area of the University of California, Davis, in the summer of 1991 on a site with no history of pepper culture or root rot. Experimental design was a split-plot arrangement with four replicates. Main plots were noninfested or infested with *P. capsici*, and subplots were the randomized irrigation treatments. Subplots were bedded rows, 1.8 m in length and 1.2 m in width, containing two plant rows. Each row contained six plants. Because of the experimental field arrangement, treatments were applied and data were collected only from one plant row. Whole plots were inoculated with a inoculum mixture of *P. capsici* isolates from California, following published procedures (23). Inoculum, grown on V8 broth-vermiculite, was rototilled into the soil to a depth of 0.20 m at a rate of 0.42 liter/m of row. Noninfested rows were rototilled without added inoculum. Planting beds were reshaped, and commercial laser-perforated bi-wall drip tape with an emitter spacing of 0.46 m was installed to deliver drip irrigation. Eight-week-old seedlings (nine- to ten-leaf stage) of the susceptible cultivar Yolo Wonder B (Petoseed Co., Inc., Woodland, CA) were transplanted to soil 2 days after soil infestation, on June 12, 1991.

Irrigation treatments applied to infested and noninfested soil were (i) furrow irrigation at 7-day intervals, in which water was delivered to furrows by garden hose and furrows were kept full for about 20 min in each irrigation event; (ii) surface drip irrigation,

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with drip tape in the plant row about 5 cm from the plants; (iii) distal surface drip irrigation, with drip tape 15 to 20 cm from the plant row; and (iv) subsurface drip irrigation, with drip tape placed 15 cm below ground level in the plant row. The amount of water applied to each drip irrigation treatment was the same, varying from 90 to 100% of the estimated evapotranspiration (ET) rates obtained from the California Irrigation Management Information System (CIMIS) network. The flow rate was 1.15 liters/h/emitter. The amount of water applied to the furrows in the furrow irrigation treatment was not quantified, but it was controlled to keep the furrows full for the time established in the treatment and not to overflow the furrows. Soil water status was measured with tensiometers inserted 0.25 m deep in the experimental rows. Midday leaf water status was measured on each plot with a pressure chamber (Model 3005; Soil Moisture Equipment Co., Santa Barbara, CA). Minimal weed control was needed, because of the arid conditions and the type of irrigation. Fertilization followed standard practices used by commercial growers. The incidence of wilting plants was assessed weekly. At the end of the season (106 days after transplanting), pepper fruits and shoots were harvested, and fresh and dry weights were determined. One day after harvest, plants were uprooted to a depth of 0.40 m, and the severity of disease symptoms on roots was rated on a scale of 0 to 5 as described before (7).

In a second field experiment, seedlings of partially resistant (7), 8-week-old pepper cv. Adra (Abbot and Cobb Seed Co., Feasterville, PA) were transplanted to soil on June 24, 1992. Experimental design was similar to the first experiment, with the following modifications: subplots were 2.4 m in length by 0.61 m in width with one plant row and 12 plants, inoculum rate was increased to 0.82 liter/m of row, spacing of the emitters in the drip tape was 0.20 m, and flow rate per emitter was 1.07 liter/h. The same four treatments described above were applied in an identical way. Soil water tensions and leaf potentials were not measured. Disease assessment was done by measuring the incidence of wilting plants sequentially and the severity of root symptoms at harvest, as above. Fruit yield and shoot weight were evaluated on control plots only. The experiment was terminated 91 days after transplanting.

Greenhouse experiments. Two experiments, analogous to the field studies, were conducted in greenhouse conditions. Fifty-five-cm-high \times 20-cm-diameter polyvinyl chloride containers filled with University of California mix soil were infested or left uninfested with the same *P. capsici* isolates used in the field. Inoculum (23) was applied at a rate of 3 ml of V8-vermiculite-mycelium/liter of soil. One day before transplanting, the columns were wetted to saturation and allowed to drain to container capacity. In one experiment, one 7-week-old seedling of cv. Yolo Wonder B was transplanted into each container on May 5, 1992. Experimental design was a randomized complete block with five single-plant replicates and eight treatments (four irrigation treatments in infested or noninfested soil). Irrigation treatments were (i) saturation of soil columns from the bottom to a height of 15 cm from the surface at 7-day intervals (soil columns were set in 35-cm-high containers of water for 4.5 h and allowed to drain freely between saturations); (ii) surface drip irrigation with the emitter within 30 mm of the plant crown; (iii) distal surface drip irrigation with the emitter set at 120 mm from the plant crown; and (iv) subsurface drip irrigation with the emitter placed at the center of the container, 150 mm below the soil surface. The flow rate on drip irrigation emitters was 0.04 liter/min. Drip irrigation schedules varied with plant size and soil water potentials and were the same for all drip irrigation treatments. Incidence and severity of disease symptoms on shoots were rated daily according to the following scale: 0 = healthy; 1 = mild wilt; 2 = severe wilt; and 3 = dead or collapsed shoot. Air and soil temperatures were recorded with thermocouple wires connected to a computerized logger (21X Micrologger; Campbell Scientific, Inc., Logan, UT), and soil tensions

were monitored daily with soil tensiometers. The experiment was terminated 14 days after transplanting.

In another greenhouse experiment, 7-week-old, partially resistant cv. Adra was transplanted into the soil columns used for the greenhouse experiment with 'Yolo Wonder B' on June 19, 1992, and no additional inoculum was added. Prior to planting, the planting mix in the columns was thoroughly homogenized to incorporate the remains of roots of the previous experiment. The soil columns were then wetted to saturation, covered with foil, and allowed to drain for 3 weeks, during which time soil temperature and moisture were monitored. Experimental design was identical to the previous experiment. Because disease was uniformly high at the end of the first experiment and because soil temperature and moisture were very similar in all units in the interval between experiments, treatments were assigned to the same columns in both experiments. The final severity of symptoms on roots and the final fresh and dry weights of fruits and shoots were determined 36 days after transplanting.

Position of inoculum experiment. Plants of 'Yolo Wonder B' and 'Adra' were grown from seed in 30 \times 20 \times 1.5-cm root boxes (width \times height \times depth). Five to six days after emergence, plants were thinned to four plants per box. Sterile, clear, mesh 30 sand was used as growth medium to facilitate drainage, lesion visibility, and access to roots. The root boxes were placed in a growth chamber set to 14-h days (160 $\mu\text{E s}^{-1} \text{m}^{-2}$), with day/night temperatures of 25/22°C ($\pm 0.5^\circ\text{C}$) and a relative humidity range of 65 to 70%. Plants were irrigated with water and half-strength Hoagland's solution (14) on alternate days. Root boxes were maintained at a 60° slant, so that many roots grew close to a removable wall. Under the conditions used, plants were at the eight- to nine-leaf stage when inoculated 7 weeks after seeding. To inoculate individual root tips at various depths, root boxes were opened and individual root tips were carefully placed onto 1 cm² pieces of Parafilm M (American National Can Co., Greenwich, CT). A suspension of 1×10^4 zoospores/ml was produced (20), and 20 μl , containing approximately 200 zoospores, were placed onto each root tip resting on the waxed film (5). Percentage of zoospore germination on CMA-R (corn meal agar amended with 10 ppm of rifampicin) was 99 to 100%. After 30 min, the waxed film with the zoospore suspension was removed, and the reassembled box was returned to the growth chamber. Mock inoculations of each cultivar with sterile, distilled water were included in all replicates. To determine the effect of placement of inoculum on lesion growth, roots were divided into two classes, 7 to 10 cm and 14 to 18 cm below soil surface, prior to inoculation. Experimental design was a randomized complete block with two cultivars, two root system lengths (four treatments), and four replications. An experimental unit consisted of one root box with four plants, and each plant was inoculated on one root tip. Total lesion growth and rate of lesion growth per day were calculated weekly for 3 consecutive weeks. Lesions were discriminated based on root discoloration. Isolations for the presence of *P. capsici* were done on CMA-R from both lesioned and seemingly healthy roots at the end of the experiment.

Statistical analysis. Disease incidence and severity and fruit yield and shoot weight were compared statistically using an analysis of variance procedure in SAS (SAS Institute, Inc., Cary, NC). Repeated analysis of variance was used for data collected sequentially (12). Single degree of freedom contrasts, corrected by the Bonferroni procedure (17), were taken for comparing the effect of irrigation method on shoot weights in infested versus noninfested soil.

RESULTS

Field experiments. In all drip treatments, the amount of water and the frequency of irrigation varied with the ET conditions and plant size. In the experiment with 'Yolo Wonder', a total of 24.93

cm of water was delivered to each experimental unit, corresponding to 98% of the crop ET estimated for the period. Within 1 month after transplanting, soil 0.25 m under plant rows was significantly drier with the furrow and distal drip emitter position than with other irrigation treatments (Fig. 1B). At the surface, soil around the stems appeared moist with the close drip emitter position and dry with the subsurface drip emitter position. When leaf water potentials were measured in noninfested plots 47 days after planting, plants receiving drip irrigation at the distal surface position had significantly ($P = 0.007$) lower potentials (-1.42 MPa) than those in the other furrow or drip irrigated treatments (-1.12 – -1.24 MPa).

In infested field plots planted with cv. Yolo, irrigation significantly ($P = 0.045$) affected disease development when data on disease incidence was averaged over time. About 10% of furrow irrigated plants developed shoot symptoms shortly after transplanting, but disease did not progress further. Conversely, disease incidence continued to increase up to 42% incidence when 'Yolo' plants were surface drip irrigated in the plant row (Fig. 1A). In contrast, no shoot symptoms and negligible root symptoms developed when infested plots were distal drip irrigated or subsurface

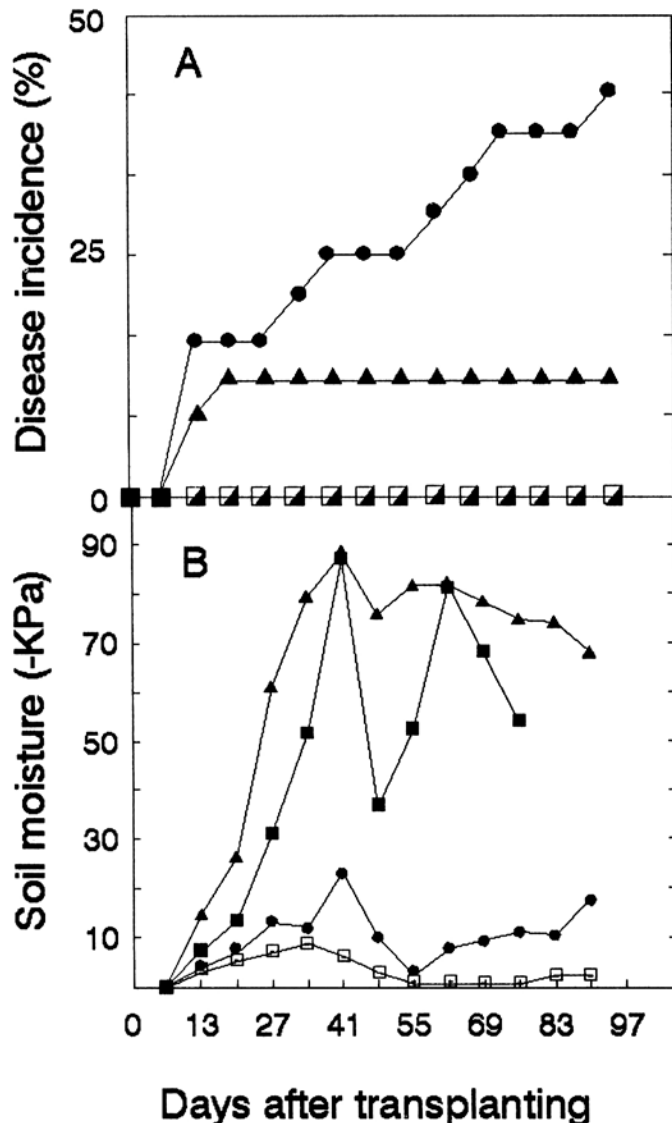


Fig. 1. A, Effect of irrigation treatment on the incidence of *Phytophthora* rot wilt symptoms in bell pepper cv. Yolo Wonder in infested field plots in 1991. B, Soil moisture content in noninfested plots at a depth of 0.25 m. ▲ = furrow irrigation, ● = surface drip irrigation, ■ = distal surface drip irrigation, and □ = subsurface drip irrigation.

drip irrigated (Fig. 1A, Table 1). In addition, yield loss and shoot weight loss in infested soil were highest with surface drip irrigation in the plant row.

In noninfested plots, only the distal drip irrigation depressed yield and plant growth (Table 1). No symptoms developed in any of the noninfested treatments.

In the field experiment with 'Adra' peppers, regardless of the fact that a more resistant cultivar and a higher inoculum dose were used, results followed the same pattern described above. Incidence of disease progressed most rapidly with surface drip irrigation in the plant row, followed by the furrow irrigated treatment. Disease progress was slowest with subsurface drip and distal surface drip emitter positions (Fig. 2, Table 2). No symptoms were observed in noninfested plots. In this experiment with 'Adra', yields in noninfested plots were superior ($P = 0.042$) in furrow irrigated plots, followed by subsurface irrigation, surface drip in plant row, and distal surface drip, in decreasing order (data not shown).

Greenhouse experiments. In the greenhouse experiment with cv. Yolo, disease became severe in infested soil, and all plants collapsed (rating = 3) within 15 days of transplant, irrespective of the irrigation treatment. Nevertheless, disease progressed somewhat more slowly with subsurface drip emitters (Fig. 3A). Irrigation effect on disease was significant ($P = 0.0531$), as was its in-

TABLE 1. Effect of irrigation treatment on final incidence of *Phytophthora* wilt symptoms on shoots, final severity of *Phytophthora* root rot on roots, and fruit yield of bell pepper cv. Yolo Wonder grown in field soil infested or uninfested with *Phytophthora capsici* in Davis, CA, 1991

Irrigation treatment	Disease		Fruit yield (kg/plot) ^x	
	Incidence on shoot (%)	Severity on root ^z	Infested soil	Noninfested soil
Furrow	13 a ^y	0.3 NS ^z	7.5 NS	8.2 a ^y
Surface drip	42 b	1.8	4.9	8.5 a
Distal surface drip	0	0.0	5.1	4.7 b
Subsurface drip	0	0.1	6.8	8.2 a

^x Relative scale of 0 (healthy) to 5 (collapsed plant).

^y Means within a column followed by the same letter are not significantly different according to Fisher's protected least significant difference test at $P = 0.05$.

^z NS = nonsignificant.

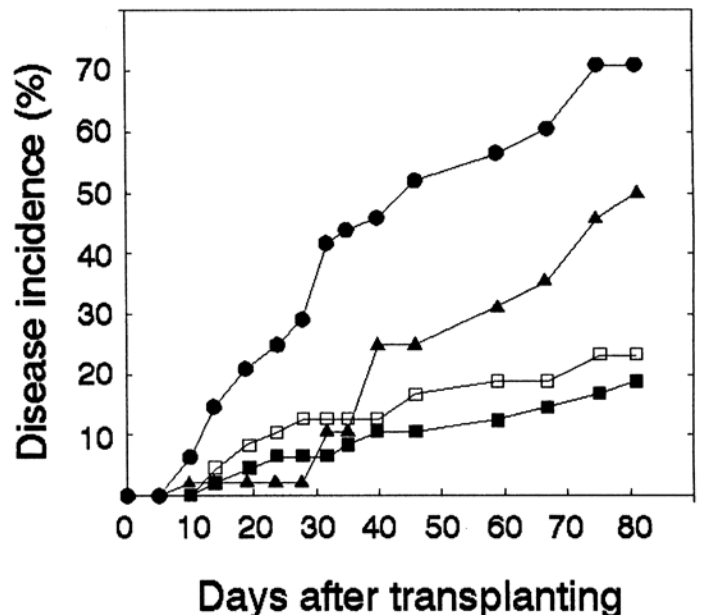


Fig. 2. Effect of irrigation treatment on the incidence of *Phytophthora* rot wilt symptoms in bell pepper cv. Adra in infested field plots in 1992. ▲ = furrow irrigation, ● = surface drip irrigation, ■ = distal surface drip irrigation, and □ = subsurface drip irrigation.

teraction with time effects ($P = 0.0438$). Final root symptoms were severe (rating = 5) for all plants in infested soil, regardless of irrigation treatment. Air and soil temperatures during the experiment ranged between 20 to 28°C and 21 to 29°C, respectively.

TABLE 2. Effect of irrigation treatment on incidence of *Phytophthora* wilt symptoms on shoots and fruit yield of bell pepper cv. Adra planted in field soil infested with *Phytophthora capsici* in Davis, CA, 1992

Irrigation treatment	Disease incidence on shoot	Fruit yield (kg/plot)
Furrow	52% a ^z	9.4 a ^z
Surface drip	69% a	3.6 bc
Distal surface drip	19% b	3.2 c
Subsurface drip	23% b	6.0 b

^z Means within a column followed by the same letter are not significantly different according to Fisher's protected least significant difference test at $P = 0.05$.

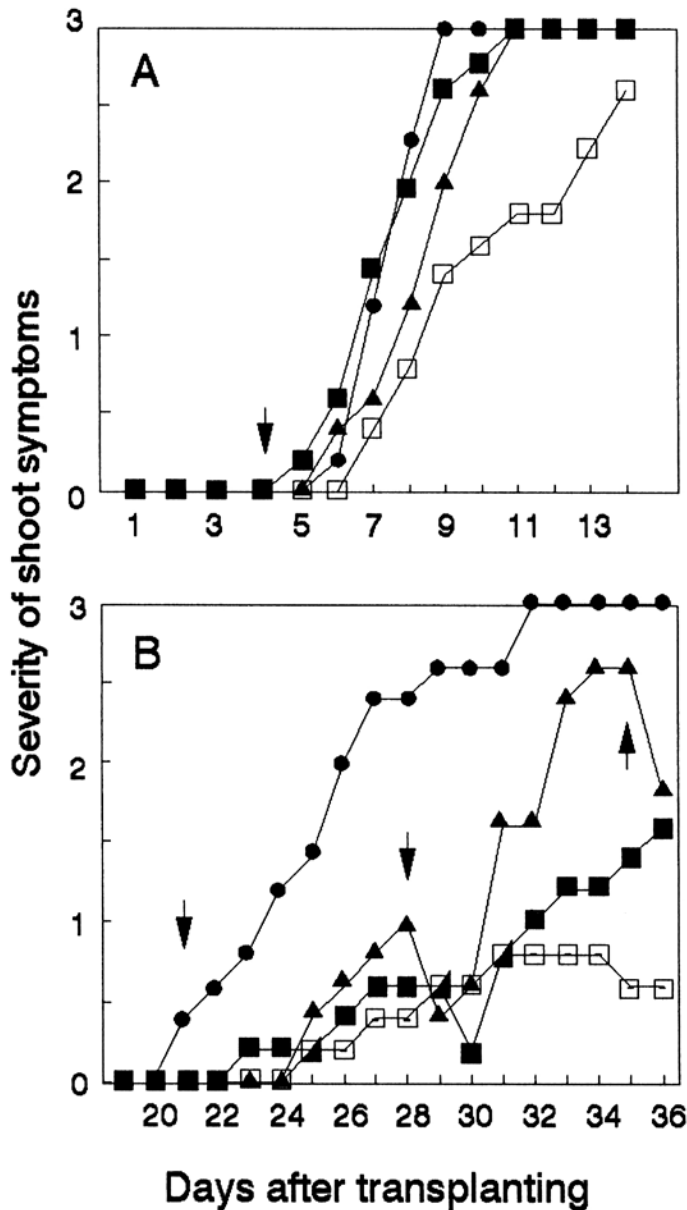


Fig. 3. Effect of irrigation treatment on the severity of *Phytophthora* rot wilt symptoms in susceptible and resistant bell pepper cultivars growing in *Phytophthora capsici*-infested containers in the greenhouse. A, Severity ratings on cv. Yolo Wonder. B, Severity ratings on resistant cv. Adra. ▲ = flood irrigation, ● = surface drip irrigation, ■ = distal surface drip irrigation, and □ = subsurface drip irrigation. Arrows indicate days when soil was flooded in the flooding treatment.

When seedlings of 'Adra' were transplanted into infested soil in the greenhouse, the rate of progress of root rot was significantly different among all four irrigation treatments ($P = 0.0015$). Sub-surface drip irrigation resulted in the lowest disease severity, followed by the distal surface drip irrigation, flood irrigation, and surface drip in plant row, in increasing order (Fig. 3B). At the conclusion of the experiment, only one out of five plants in the subsurface treatment had shoot symptoms, but all plants in the other irrigation treatments had wilt symptoms. In infested soil, 'Adra' plants irrigated close to the crown had the most severe symptoms on roots (Fig. 4) and the largest reduction in fresh (Fig. 4) or dry (data not shown) shoot weights. In the absence of the pathogen, fresh weights of shoots were not affected significantly by irrigation treatment (Fig. 4), but use of furrow irrigation or surface drip irrigation significantly depressed yields if the pathogen was present (Table 3).

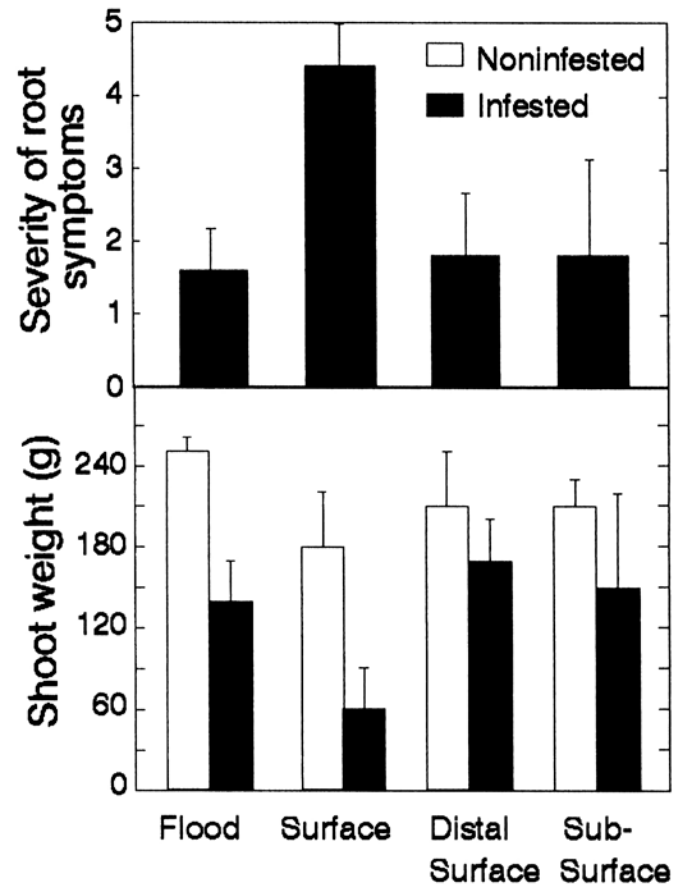


Fig. 4. Final severity of *Phytophthora* root rot symptoms on roots and shoot fresh weights of bell pepper cv. Adra grown in *Phytophthora capsici*-infested greenhouse containers and subjected to four irrigation treatments. Flood treatment consisted on soil saturation at 7-day intervals: in the surface drip treatment, emitters were located 30 mm from plant; in the distal surface drip treatment, emitters were located 120 mm from plant; and in the subsurface drip treatment, emitters were placed 150 mm below soil surface. Lines above bars represent standard deviations.

TABLE 3. Single degree of freedom contrasts for fresh shoot weights of bell pepper cv. Adra between same irrigation treatment performed in soil infested or noninfested with *Phytophthora capsici* on greenhouse container-grown plants in Davis, CA, 1992

Irrigation treatment	df	Sum of squares	P^z
Furrow	1	26832.4	0.0004**
Surface drip	1	39187.6	0.0004**
Distal surface drip	1	5475.6	0.1916
Subsurface drip	1	8526.4	0.0612

^z After Bonferroni procedure (17).

Environmental variables were as in the experiment with susceptible cv. Yolo. Volume of water varied with the plant growth stage. The flooding procedure in the flood treatment was performed three times with cv. Adra (Fig. 3, arrows). Soil moisture tensions at 10 cm depth tended to be higher with subsurface drip irrigation and lower with distal surface drip irrigation (data not shown).

Position of inoculum experiment. Growth stopped on diseased roots shortly after inoculation. Once root growth stopped, the inoculated tip usually withered and did not resume growth. Mock inoculations with water also stopped root growth, but growth resumed at normal rates (8 to 9 mm/day) within 4 days. All of the inoculated root tips became diseased, and the dark lesions that developed on roots were easily distinguished from healthy roots 4 days after inoculation. Reisolations of *P. capsici* from diseased roots confirmed the close relation between root discoloration and infection.

Depth of the inoculated root tip from the sand surface did not affect the speed at which lesions grew upwards from tips in either cultivar (Fig. 5). Rate of lesion growth in 'Yolo' was constant (6.5 to 7.5 mm/day) for 3 consecutive weeks, irrespective of the position of initial inoculation, and lesions grew indeterminately, advancing either from lateral to primary roots or from primary to lateral roots. Lesions could reach up to the crown and stem regions. Lesions in stems grew at a faster rate (9.1 mm/day) than those in roots. The increase of the rate of lesion growth at 21 days in 'Yolo' plants inoculated at a depth of 7 to 10 cm (Fig. 5, *) was because of the growth of lesions on the stems of some plants. Lesions originating from secondary infections were rarely observed and not until 14 days after inoculation. Secondary lesions were always located at depths lower than the point of inoculation.

Lesions grew more slowly on 'Adra' roots than on 'Yolo' (Fig. 5). In addition, growth rates decreased with time from 3.0 to 3.6 mm/day in the first week to 1.0 to 1.6 mm/day in the second and third weeks after inoculation. Individual lesions apparently stopped growing in about half the 'Adra' plants 2 to 4 weeks after inoculation (data not shown). Lesions never reached the crown of 'Adra' plants during the course of the trials.

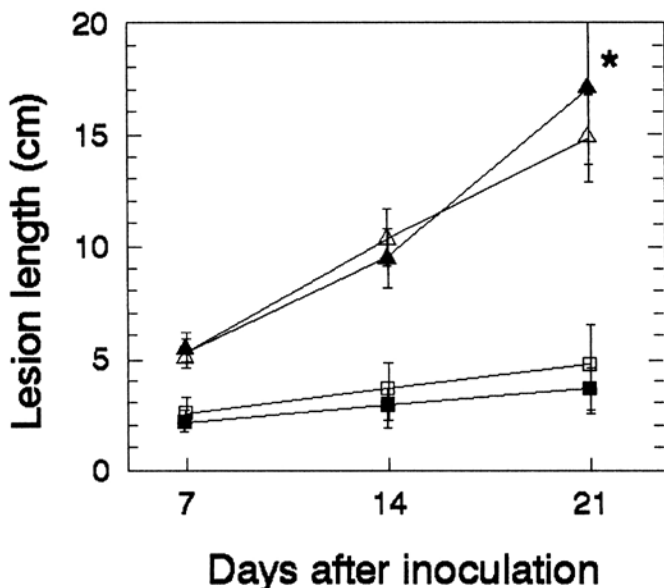


Fig. 5. Length of *Phytophthora* root rot lesions in individual roots of cv. Adra (squares) and cv. Yolo Wonder B (triangles) over time. Root tips were inoculated at a length of 7 to 10 cm (solid symbols) or at 14 to 18 cm (open symbols) below the soil surface. Lines above and below data points represent plus and minus one standard deviation at each date. The * indicates a measurement including some lesion growth on stems.

The position of drip irrigation emitters relative to the plant had a major effect on the development of *Phytophthora* root and crown rot in bell pepper. In field experiments simulating normal growing conditions, as well as in greenhouse experiments, drip irrigation close to the stem or crown resulted in high disease levels (Figs. 1, 2, and 3). Severity of root symptoms, yield losses, and reductions in shoot weights (Fig. 4, Tables 1 and 2) also were enhanced when drip irrigation emitters were close to the plant. In contrast, less disease developed when drip emitters were placed more distal to the plant. Data were consistent for the two cultivars with different degrees of resistance to root rot. Most of the oscillation in symptom severity on 'Adra' during the course of the greenhouse experiment (Fig. 3B) can be ascribed to fluctuations in the environmental variables influencing plant water status. Symptoms increased on hot, clear days and decreased on the days following soil saturation in the flooded treatment.

In noninfested field plots, the distal surface drip irrigation resulted in plant water stress, lower yields, and smaller plant growth. Consequently, possible gains from controlling *P. capsici* root rot of pepper by altering the location of drip emitters may be outweighed by the losses due to drought stress if water is delivered too far from the plants. In the greenhouse, placing drip emitters 120 mm from stems did not impair plant development (Fig. 4), because ET was more limited than in the field and because distal surface emitter position was closer to the plants than in the field.

Only low levels of root rot developed on cv. Yolo under furrow irrigation in the field in 1991, and disease did not continue to increase after the first 3 weeks (Fig. 1A). Also, disease did not develop in the distal surface or subsurface drip treatments. The milder disease levels observed in this season can be attributed mainly to the lower inoculum levels used that year. With simulations closer to normal field conditions, high levels of disease usually develop in 'Yolo Wonder' pepper when a 7-day furrow irrigation schedule is applied (7). On the other hand, the higher inoculum level used in 1992 resulted in severe disease in the furrow irrigated treatment and also in considerable levels in the other treatments, even with a partially resistant cultivar (Fig. 2). In addition, when soil was saturated once every 7 days in the greenhouse experiments, high levels of root rot developed (Fig. 3).

Depth or position of inoculated root tips had no effect on the rate of lesion growth on roots of susceptible or resistant cultivars (Fig. 5). There was, however, a marked cultivar effect on lesion growth rate, which was also reduced with time (sometimes to a complete halt) on cv. Adra. Thus, when lesions started nearer to the crown, disease could cause crown death and plant collapse, even when there were healthy roots below. Lesion growth rate on roots of 'Yolo' approached those reported for the growth rate of *P. capsici* in culture (1.1 to 1.2 cm/day) (16), an indication of the high susceptibility of this cultivar. In preliminary experiments, 2 to 20 zoospores per point of inoculation resulted in successful infections in 'Yolo' root tips. The observation that rate of lesion growth on roots remained high in susceptible cv. Yolo, but tended to decrease with time in resistant cv. Adra, is similar to reported results with stem inoculations (13,18,21). Gil et al. (13) found no reduction in the rate of lesion growth in the stems of susceptible cv. INIA from the first to the second week (6.8 to 7.8 mm/day), but lesion growth was reduced on partially resistant cv. Phyto 636 in the same period (2.3 to 0.5 mm/day). A progressive induction of resistance, as described initially for stems of some resistant pepper genotypes (18,19), may also occur in the roots of 'Adra'. The period of enhanced susceptibility reported to occur in pepper at a very young age (18,20) was avoided in this experiment, by the use of plants at the eight- to nine-leaf stage at inoculation.

In the field, symptom development increased shortly after periods of irrigation. Evidently, irrigation allows the pathogen to form

many sporangia and zoospores and, thereby, promote root infection. It is likely that the placement of drip emitters near plant stems allow more numerous infections at vital parts of the root system and crown. Consequently, control of the disease in the field was achieved, at least partially, by the maintenance of soil moisture levels unfavorable to sporangium germination at important locations in the soil, i.e., near the crown region. Drier conditions near the crown also likely reduced zoospore mobility in this region of the soil (10).

In conclusion, in the absence of rain, *P. capsici* root rot of pepper could be effectively reduced by locating drip emitters away from the stems of plants. A subsurface location 150 mm below the soil surface yielded significant disease reduction, while maintaining optimum plant productivity in the absence of *P. capsici*. Pepper genotypes with partial resistance to *P. capsici* have been shown to wilt under excessive irrigation (7). Use of a subsurface drip system with a choice of resistant cultivars may limit the impact of this disease.

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