Effects of irrigation method on chile pepper yield and *Phytophthora* root rot incidence

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Abstract

A field experiment was conducted in 1995 and 1996 to examine the effects of different irrigation methods on yields and *Phytophthora* root rot disease of chile plants (*Capsicum annum* New Mexico ‘6–4’). Three irrigation methods, daily drip, 3-day drip, and alternate row furrow irrigation, were applied to plots infested with *P. capsici* and uninfested plots. For both years, the drip irrigation (either daily or 3-day) created higher marketable green chile yields than the alternate row furrow irrigation (*p* < 0.05), and the yields between the daily and 3-day drip irrigation were statistically similar. The effect of irrigation on marketable combined yields was similar to that on green chile yields. In 1995, root rot disease incidence in the infested plots was significantly higher under alternate row furrow irrigation than for daily and 3-day drip irrigation. There was no disease development in the uninfested plots regardless of the irrigation method. The disease decreased green chile yield by 55% (*p* < 0.1), and combined yield (green + red chile) by 36% (*p* < 0.1) in 1995 compared to that in uninfested plots in alternate row furrow irrigation. In 1996, however, no disease occurred in any treatment. The results suggested that drip irrigation increases chile yield through providing either favorable soil moisture conditions or unfavorable conditions for *Phytophthora* propagation. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Water stress is one of the most influential factors contributing to crop yield loss. Insufficient water supplied to a crop during critical stages of growth causes substantial
yield loss. (Tuner, 1990; Singh et al., 1991). The measurements of plant water status can be used to evaluate if crops suffer from moisture stress. One of the measurements is the crop water stress index (CWSI) developed by Idao et al. (1981). The relationship between yield and CWSI was reported on spring barley (Tubaileh et al., 1986), alfalfa (Abdul-Jabbar et al., 1985), and sweet lime (Sepaskhah and Kashefipour, 1994).

In arid or semi-arid areas, crop growth is mainly dependent on irrigation. Irrigation methods and management are of importance to soil water status, and thus, to plant water status. Inappropriate irrigation could result in water stress. Drip irrigation provides more efficient water use for crops than furrow irrigation because drip irrigation applies frequent small amounts of water to the root zone and reduces adverse effects of cyclic over-irrigated and water stress commonly caused by furrow irrigation. Many studies and reports have addressed that yield and quality of hop (Humulus Lupulus L.), potato (Solanum tuberosum) tuber, tomato, cotton, and cantaloupe could be improved with drip irrigation (Bernstein and Francois, 1973; Sammis, 1980; Wample and Farrar, 1983; Wood, 1988). Reports about the effect of irrigation on chile pepper yields are few (Wierenga and Hendrickx, 1985).

Chile peppers are sensitive to soil water status. Bell peppers had higher pod yield when soil water potential was high (Shmueli and Goldberg, 1972) and the final yield would decrease if limited water was applied during the period of rapid growth stage of a trickle-irrigation chile (Beese et al., 1982). Wierenga and Hendrickx (1985) studied the relationship between several water application amounts and the yield responses of trickle-irrigated chile pepper (Capsicum annuum ‘New Mexico 6–4’), and found that the maximum green chile yield was obtained with an approximate crop evapotranspiration of 86.1 cm in the Las Cruces, NM area.

Diseases also occur due to inappropriate irrigation. Chile root rot is a common disease of chile peppers in New Mexico. This disease is caused by a soil fungus, Phytophthora capsici. There are many reports about P. capsici disease on peppers and other plants in the United States and worldwide. Fungicides can be used to control P. capsici; however, their effectiveness is reduced if the environmental conditions are favorable for fungal growth (Biles et al., 1992).

Epidemics of root and crown rot caused by Phytophthora spp. largely depend upon climate and soil conditions (Duniway, 1976). Rainfall and soil moisture status are the important factors stimulating Phytophthora root and crown rot (Wilcox and Mircetich, 1985a; Bowers et al., 1990; Cafe-Filho and Duniway, 1995). Since irrigation affects soil water conditions, the incidence of root rot disease can potentially be modified by changing irrigation practices (MacDonald and Duniway, 1978; Kenerley et al., 1984; Matheron and Mircetich, 1985; Grove and Boal, 1991). The frequency of furrow irrigation and flooding duration had a direct relation to Phytophthora diseases (Wilcox and Mircetich, 1985b; Bowers and Mitchell, 1990). Higher disease incidence and mortality of pepper plants occurred with more frequent irrigation and longer duration of flooding (Bowers and Mitchell, 1990; Cafe-Filho and Duniway, 1995).

Zoospore release, and sporangia formation of P. capsici are critical forms causing pepper root rot disease. To maintain the life cycle of most Phytophthora spp., the
condition of wet–dry cycles in soil is required (Duniway, 1975a, b; Gisi et al., 1980; Wilcox and Miretich, 1985a). In practice, rainfall and periodic furrow irrigation usually provide a wet–dry cycle in soil, favoring sporangia formation during the drying period and zoospore release during the flooding (MacDonald and Duniway, 1978; Kuan and Erwin, 1982; Bowers and Mitchell, 1990). It is likely that the disease can be greatly reduced if soil water status can be maintained at a relatively steady condition which prevents either sporangia production or zoospore release. This goal may be achieved by using drip irrigation.

In the present research, a field experiment was conducted to determine if root rot in chile pepper plants caused by \textit{P. capsici} could be controlled by elimination of favorable conditions for zoospore release and sporangia formation by applying drip irrigations daily or every 3 days as compared with using alternate row furrow irrigation. Meanwhile, yields in chile pepper were evaluated under the three different irrigation methods.

2. Materials and methods

2.1. Field preparation

The experimental field was located at the Fabian Garcia Agricultural Research Center, Las Cruces, NM. The soil-type was a Brazito sandy loam (mixed, thermic typic torripsamments) with a pH of 7.2. The field had been fallow for 15 years before the experiment in 1995. In November 1994, the field was custom plowed, laser leveled, and divided into five blocks (18.3 m long 15.2 m wide). The field was raised as beds and the bed spacing was 1.0 m.

2.2. Experimental treatments

The experimental design was a randomized complete block design (RCBD) with three irrigation levels (daily drip irrigation, 3-day drip irrigation, and alternate row furrow irrigation) and two \textit{Phytophthora} levels (non-infested and infested). The treatments were randomly applied to each block, and the treatment rows were separated by 2–3 border rows. The experiment began in 1995 and was repeated in 1996.

2.3. \textit{Phytophthora} inoculum preparation and field infestation

The 6143 strain, A1 compatibility-type of \textit{P. capsici} isolated from diseased chile plants was used as the pathogen for this experiment. The inoculum was prepared by transferring the isolate from V8 juice agar to quart jars containing vermiculite amended with 350 ml of V8 broth, and incubated at 24°C for 4 weeks (Ristaino et al., 1992). On 11 April 1995 the vermiculite inoculum, containing sporangia and mycelia, was placed on both sides of the plants 15 cm from the center of the bed and 5 cm deep at a rate of 360 ml m$^{-1}$. Since a leaf disk assay based on Hord and Ristaino (1992) showed the existence of \textit{P. capsici} in soil, the field was not re-infested in 1996.
2.4. Chile planting

Eight-week old chile seedlings, *Capsicum annum* ‘New Mexico 6–4’, were transplanted on treated rows on 24 April 1995 and 15 April 1996. Two lines per bed were planted in a staggered arrangement. Plants were placed 7.5 cm from the center with a 60 cm spacing between two adjacent plants on the same side and a 30 cm spacing between two adjacent plants on opposite sides of the bed. The drip system was operated daily for 2 h during the establishment of the transplants, and furrow rows were irrigated every 3–4 days in the first week. Beginning the second week after transplanting, drip irrigation was reduced to every 2 days, and furrow irrigation to every 5 days. The irrigation scheduling for the experiments began on 24 May 1995 and on 14 May 1996 after the establishment of the plants.

2.5. Irrigation system installation and irrigation application

The drip tubing (T-tape) with emitters every 30 cm was buried 20 cm below the soil surface in the center line of each row and connected to the submain line through flexible tape (2 cm in diameter) with twist locks. Water was applied at a rate of 5.0 l h\(^{-1}\) m\(^{-1}\). The drip irrigation system was operated by a computer that scheduled water application. The amount of water applied every day or every 3 days through drip irrigation was determined using potential evapotranspiration (ET\(_0\)) and a crop coefficient (K\(_c\)). ET\(_0\) was calculated using weather data and the Penman equation referenced to grass (Sammis et al., 1985), and K\(_c\) was estimated by the Arizona Irrigation Scheduling (AZSCHED) model (Fox et al., 1992) using growing degree days (GDD). The product of ET\(_0\) and K\(_c\) is an estimate of crop evapotranspiration (ET\(_c\)) under non-water stress conditions (Eq. (1)). The actual amount of water applied for drip irrigation was determined by dividing the calculated ET\(_c\) by an irrigation efficiency of 0.8.

\[
ET_c = ET_0 \times K_c \tag{1}
\]

The furrow irrigation system included a buried main, a submain line, and risers with valves on the end to deliver water to each furrow-irrigated treatment. The system was controlled manually. The irrigation date for the furrow system was predicted by the AZSCHED model (Fox et al., 1992). Actual irrigation amounts were recorded by a flowmeter on both the drip and furrow irrigation systems after each irrigation event.

The total amount of irrigated water for daily, 3-day drip and furrow irrigation is 1170, 1220, and 1240 mm, respectively, in 1995, and 1180, 1190 and 1490 mm in 1996.

2.6. Field management

Several weeks before transplanting, the field was irrigated to allow germination of weed seed, and the weeds were killed with glyphosate\(^{\text{R}}\). After transplanting, weeds were controlled manually. Orthene\(^{\text{R}}\) was applied in May to control aphids and thrips, and
Sevin® was applied in June to control leafhoppers, both at a rate of 8 ml l⁻¹ during the two growing seasons.

Nitrogen fertilizer (URAN) was applied with the irrigation water by injection at a concentration of 32 mg l⁻¹ (397 kg ha⁻¹) of NO₃-N. Before transplanting, phosphorous (P₂O₅) was applied as banded fertilizer on both sides of the row at a rate of 67.3 kg ha⁻¹.

2.7. Disease data collection

Disease incidence was monitored weekly before 14 June and daily thereafter by counting the diseased plants in every plot. Plants were rated from 0 to 3 where zero indicated healthy plants, 1 = incipient wilting plants, 2 = stem necrosis and 3 = dead plants. Diseased plants with a rating of 3 were sampled to confirm the presence of *P. capsici* by culturing and inoculating chile seedlings in a greenhouse. While counting the number of diseased plants, the number of plants with curly top disease and other disorders was also recorded.

2.8. Yield measurements

Green chile was harvested twice during the growing season. The first harvest was on 13 July 1995 and on 16 July 1996. The second harvest was on 2 August 1995 and on 15 August 1996. Harvested pods were dark green, glossy, firm and longer than 10 cm. In 1995, chile was picked from an area 3.0 m × 1.0 m for drip-irrigated plots, and from an area 6.0 m × 1.0 m for alternate row furrow-irrigated plots. In 1996, chile was picked from a 3.0 m × 1.0 m plots for all treatments. Unmarketable fruits were classified as exhibiting sunburn damage, blossom end rot, misshapen fruits, disease symptoms, and other defects (less than 10 cm length or dehydrated pods). The green chile yield data included total and marketable fruit yields.

Red chile was harvested on 25 October 1995 and on 31 October 1996. All red pods were harvested except small and rotten ones, and dried at 55–60°C. Marketable yield was obtained by culling pods which had severe signs of sunburn and black mold (*Alternaria alternata*).

Combined yield (green + red chile yield) was obtained by converting dry red chile yield to wet yield using a wet/dry ratio of 8 (Gore and Wilken, 1995).

2.9. Canopy temperature and CWSI measurements

Canopy temperature was measured using an infrared thermometer (Model 210, Everest Interscience) in August 1995 to evaluate water stress under different irrigation methods. The measurements were conducted from 12:00 to 2:00 p.m. on sunny days when daily radiation was highest. Canopy temperature (*Tc*) was measured by holding the infrared gun about 0.5 m above chile plants at an angle of 35–45°C above the horizon. Ten measurements were taken, five toward the east and five toward the west, and the average canopy temperature was calculated. Air temperature (*Ta*) and wet bulb temperature were measured with a psychrometer (Model H331, Weather Measure Corp.) to calculate vapor
pressure deficit (VPD). By plotting \((T_c - T_a)\) versus VPD, we obtained the lower base line which represented non-stress conditions. The upper base line is a horizontal line representing no transpiration. CWSI was calculated by determining the relative distance between the lower base line and the upper base line regarding the point of \((T_c - T_a)\) (Saddiq, 1983).

2.10. Soil moisture and rainfall data

The water content in the soil profile was monitored biweekly on three blocks using a neutron probe (3226 series, Troxler Electronic Laboratory) at depths of 30, 60, 90, 120, and 150 cm. Access tubings were installed in the middle of the beds about 15 cm away from adjacent plants.

2.11. Data analysis

Yield and disease data were subjected to analysis of variance using the Statistical Analysis System (SAS). Covariance analysis was performed to account for high incidence of curly top virus in 1995. Least square means were used to locate the effects of irrigation, infestation, and their combination. CWSI was contrasted among irrigation methods on each measurement date.

3. Results

3.1. Influence of irrigation methods on chile yields

Total and marketable green chile yields were higher for both daily and 3-day drip irrigation than for alternate row furrow irrigation in 1995 and 1996 regardless of infestation, but yields were similar between daily and 3-day drip irrigation (Figs. 1 and 2). In 1995, both total and marketable green chile yields were 66% greater from daily drip irrigation treatments, and 60% greater for 3-day drip irrigation, respectively, than alternate row furrow irrigation. In 1996, the marketable green yield increased by 43% for the daily drip irrigation and 45% for the 3-day drip irrigation compared to yield for alternate row furrow irrigation.

The effect of irrigation methods on dry red chile yield was different between years. In 1995, the effect was similar to green chile yield. Drip irrigation increased dry red chile yield (both total and marketable yields; \(p \leq 0.05\)), and there was no difference between the daily and 3-day drip irrigation under the same infestation level. However, in 1996, there was no significant difference among the three irrigation methods (Figs. 1 and 2) on dry red chile yield.

The response of combined yields to irrigation methods was similar to green chile yield. Daily and the 3-day drip irrigation increased total as well as marketable combined yield as compared to the alternate row furrow irrigation. There was no difference in yield between drip irrigation treatments (Figs. 1 and 2). Drip irrigation increased both total and marketable combined yield by 42% in 1995 and 20% in 1996.
Fig. 1. Total green (A), red (B), and combined (C) chile yields for each treatment in 1995 and 1996. Id = Daily drip irrigation; It = 3-day drip irrigation; If = Alternate row furrow irrigation; P0 = Non-infested with *P. capsici*; P1 = Infested with *P. capsici*. Yields under three irrigation methods were compared at 95% confidence level.
Fig. 2. Marketable green (A), red (B), and combined (C) chile yields for each treatment. Id = Daily drip irrigation; It = 3-day drip irrigation; If = Alternate row furrow irrigation; P0 = Non-infested with Phytophthora; P1 = Infested with Phytophthora. Yields under three irrigation methods were compared at 95% confidence level.
3.2. Influence of Phytophthora infestation on chile yields

In 1995, total green yield (11.6 t ha\(^{-1}\)) and combined yield (24.1 t ha\(^{-1}\)) under the non-infested furrow irrigated treatment were higher than yields (5.2 t ha\(^{-1}\) for green, 15.2 t ha\(^{-1}\) for combined) under the infested furrow-irrigated treatment (Fig. 1). The infestation treatment decreased alternate row furrow-irrigated green chile yield by 55% and combined yield by 36%. However, there was no difference in yields between infested and non-infested treatments for the daily and 3-day drip irrigations at a 90% confidence level. Total dry red chile yield did not show any difference between infested and non-infested treatments for all irrigation treatments at the 90% confidence level. In 1996, the infested treatments did not reduce yield among the three irrigation treatments.

In 1995, an unexpected epidemic of curly top virus prevailed in the field and affected green and combined yields (\(p < 0.05\)). The final incidence of this disease in the field ranged from 25 to 46% among treatments. The yield loss caused by the curly top virus could be seen in the field. The plants with the virus were stunted, chlorotic, and bore small or no fruit.

3.3. Disease incidence

In 1995, the plants showed no sign of *Phytophthora* disease incidence in the treatments without inoculum, regardless of irrigation method. In infested plots, the final disease incidence was 3.3% for daily drip irrigation, 1.5% for 3-day drip irrigation, and 36.8% for alternate row furrow irrigation (Fig. 3).

![Fig. 3. Disease incidence in chile plots inoculated with *P. capsici* under different irrigation methods (1995).](image)
In the growing season of 1996, the *Phytophthora* disease was not found in either the infested or uninfested treatments regardless of the irrigation method.

### 3.4. Estimated CWSI, moisture content in soil profile, and rainfall

Alternate row furrow irrigation had the highest CWSI among the three irrigation methods in several irrigation cycles measured in August 1995 (Fig. 4), indicating that the plants grown on the alternate row furrow-irrigated plots suffered greater water stress than those grown on the drip-irrigated rows. The difference in CWSI between alternate row furrow irrigation and drip irrigation was significant \((p < 0.05)\) among the irrigation cycles except on 27 August. The average CWSI was 0.65 for alternate furrow irrigation, 0.20 for daily drip irrigation, and 0.25 for 3-day drip irrigation in August.

Average soil moisture content was lower under alternate row furrow irrigation than under daily and 3-day irrigation (Fig. 5). Since only the available water around the root zone is important in terms of crop use, soil water depletion level, difference between the field capacity (FC) and soil water content in percentage of FC, in the root zone would be a better way to evaluate whether the plants suffer water stress. The depletion level for the alternate row furrow irrigation, in general, was higher than for drip irrigation throughout the growing season, indicating that less available water occurred for furrow irrigation than for drip irrigation in the root zone (Table 1).
Heavy rainfall is one of the important factors causing severe root rot in chile (Shannon, 1989; Ristaino, 1991). Heavy rainfall is considered an event greater than 20 mm (Ristaino, 1991). However, rainfall did not play an important role in this experiment, because only 120 mm cumulative rainfall and three events greater than 20 mm occurred in 1995, and 140 mm cumulative rainfall and two events greater than 20 mm occurred in 1996 (Fig. 5).
4. Discussion

4.1. Influence of irrigation methods on chile yield

Seasonal crop evapotranspiration ($ET_c$) had a positive linear relationship with yield (Sammis and Samani, 1991). Wierenga and Hendrickx (1985) found that a maximum yield of green chile (‘New Mexico 6–4’, 33.2 t ha$^{-1}$) grown in Las Cruces, NM in 1981 was obtained with a seasonal $ET_c$ of 861 mm under drip irrigation. This yield was higher than total green yield (23.0 t ha$^{-1}$) in our experiment of 1995 for drip irrigation although the water applied that year reached 120 cm. The 2 years had similar weather conditions, with the cumulative heat units of 1709$^\circ$C in 1995 during the growing season and of 1777$^\circ$C in 1981 during the same period based on the maximum and minimum daily temperature with the base temperature of 30.5$^\circ$C (if the daily maximum temperature was greater than 30.5$^\circ$C, 30.5$^\circ$C replaced it) and cut-off temperature of 5$^\circ$C (if the minimum daily temperature was lower than 5$^\circ$C, 5$^\circ$C replaced it) for the chile plant (Fox et al., 1992). Fertilizer stress was not a limiting factor for both drip and alternate furrow irrigation with a total 384 kg ha$^{-1}$ of NO$_3$–N for the drip irrigation and 397 kg ha$^{-1}$ of NO$_3$–N for alternate furrow irrigation. However, only 130 kg N ha$^{-1}$ was taken up by the plants based on a harvest index of 0.61 and a concentration of N in the plants of chile (Al-Jamal, 1995). Phosphorous was also unlikely to have been a limiting factor since 67.3 kg ha$^{-1}$ P$_2$O$_5$ was applied which was 1.5 times the recommended rate for a furrow irrigation system (Glover and Baker, 1990). The drip yield in the study was also 1.5 times the average furrow-irrigated yields for Dona Ana County, NM (Gore and Wilken, 1995).

High incidence of curly top virus during the season of 1995 could have contributed to the yield loss as compared with Wierenga and Hendrickx’s result (1985). CWSI indicated that the plants under the drip irrigation suffered 20 (daily) to 25% (3-day) water stress (Fig. 4) even though the water applied was in excess of maximum ET obtained by Wierenga and Hendrickx (1985). Due to the high incidence of curly top virus, the plants chosen for canopy temperature measurement had the virus infection. The curly top virus would decrease transpiration and water use of chile plants, resulting in water stress of
plants. This explained the high CWSI under drip irrigation. The curly top virus could also reduce the capability of photosynthesis of chile plants due to small and wilted leaves, which caused yield loss. Consequently, curly top disease in 1995 might be the factor responsible for the reduction of chile yield under drip irrigation.

In 1996, the average green chile yield (30.3 t ha⁻¹) under drip irrigation was compatible with the maximum yield (33.2 t ha⁻¹) obtained by Wierenga and Hendrickx (1985), indicating plant growth was not limited by fertilizer, soil water or disease factors.

In both years, drip irrigation increased chile yield as compared with the alternate row furrow irrigation. CWSI can indicate whether plants suffer water stress or not. The increase in CWSI from 0.22 for the drip to 0.65 for the furrow in 1995 indicated that the furrow-irrigated plants suffered an additional 43% decrease in ET due to soil moisture stress. The estimated seasonal ET for furrow irrigation was 300 mm [86 cm × (1 − 0.65)] based upon CWSI. This ET resulted in an estimated green chile yield of 8.0 t ha⁻¹ based upon Wierenga and Hendrickx’s water production function (1985), which agreed with the yield in this study (11.6 t ha⁻¹) under non-Phytophthora treatment.

4.2. Disease incidence

Drip irrigation controlled root rot caused by *P. capsici* in 1995 (Fig. 2). This was probably due to a lack of wet–dry cycles for sporangia formation and zoospore discharge. The life cycle of *Phytophthora* requires moist soil for sporangia production but saturated conditions for zoospore release (Duniway, 1976, 1979, 1983; MacDonald and Duniway, 1978; Bernhardt and Grogan, 1982). However, drip irrigation, especially light frequent application such as the daily treatment in our experiment, usually would not create saturated conditions in the soil except in the vicinity of the emitter during irrigation. The soil matric potential is lower the farther the soil volume is from the emitter (Goldberg et al., 1976).

In the present experiment, it is reasonable to speculate that the soil layer of 5 cm depth at which the inoculum was applied could not be saturated because of the buried depth of drip tubing (20 cm below soil surface) and low emitter discharge rate (5.0 l h⁻¹ m⁻¹). As a result, the life cycle of *P. capsici* might be interrupted at the stage of zoospore release under the daily drip irrigation, causing decreased secondary inoculum production and dispersal which is a major route for multiple infection of plants (Bernhardt and Grogan, 1982; Duniway, 1983).

The distribution of soil moisture under 3-day drip irrigation is similar to that under daily drip irrigation. Although the time of operation was three times that of daily drip irrigation, the soil layer of 5 cm depth was likely to be unsaturated during the irrigation operation because of low emitter discharge rate. Again, the 3-day drip irrigation could not create saturation to implement zoospore discharge in the experiment of 1995. However, our finding that drip irrigation controlled *Phytophthora* disease in 1995 contradicted Ristaino’s results (1991). She found that more frequent drip irrigation (3 times per week for 4 h duration) increased root and crown rot significantly as compared with less frequent drip-irrigated treatment when greater than 2.0 cm of rainfall occurred only twice during the growing season. The distance between drip tubing and the application site of the inoculum might explain the difference. In Ristaino’s research (1991), the inoculum was applied at the same depth as drip tubing was buried (10 cm below soil surface), and
likely provided saturated conditions for the zoospore release during irrigation, whereas, the drip tubing was buried at 20 cm depth and the inoculum was applied at less than 5 cm depth in our experiment. Although our experiment suggested that the Phytophthora disease could be controlled by both daily and 3-day drip irrigation, less frequent drip irrigation was recommended for practical implication because the distribution of the pathogen was likely to be relatively uniform in the field with a history of Phytophthora, and inoculum density was greater near the drip line (Ristaino et al., 1992). Less frequent drip irrigation could provide less saturation periods.

In 1995, the alternate row furrow-irrigated chile had a disease incidence (Fig. 3) which agreed with other research on various furrow-irrigated plants, such as walnut (Matheron and Mircetich, 1985), processing tomatoes (Ristaino et al., 1988), cherry (Wilcox and Mircetich, 1985b), Fraser fir seedlings (Kenerley et al., 1984), and pepper (Bowers and Mitchell, 1990). The occurrence of the disease caused by flooding irrigation could be explained by the favorable condition for zoospore release of Phytophthora. The prolonged duration of flooding increased the occurrence of root rot in cherry (Wilcox and Mircetich, 1985a) and Fraser fir seedlings (Kenerley et al., 1984). We observed 4–5 h standing water occurring in the furrows after each application, which was likely to favor zoospore release of P. capsici.

As discussed in the previous section, furrow irrigation usually caused the problem of water stress. Increasing the frequency of furrow irrigation would relieve the stress; however, the number of wet–dry cycles would increase correspondingly. The possible resultant could be more disease.

Farmers have choices of irrigation methods. Drip irrigation is likely to be the optimal method to control P. capsici disease and to maintain high yield. However, farmers using furrow irrigation need to choose either decreasing the frequency of irrigation to control the disease but increasing water stress or increasing the frequency of irrigation to decrease water stress but increasing disease incidence. Both water stress and the disease cause yield loss. If furrow irrigation is selected, the problem is how to obtain a balance between water stress and disease occurrence.

No disease developed in the field in 1996 under furrow irrigation, even in the infested treatment. The reason could be low inoculum units without re-infesting the field.

5. Conclusions

Chile yield could be increased greatly and root rot caused by P. capsici could be controlled by the drip irrigation designed in the present experiment. In practice, less frequent drip irrigation might be a better method to control the disease, because the inoculum near the emitters would be exposed to a lesser saturation period (Ristaino et al., 1992). Although alternate row furrow irrigation might be a good way to limit disease incidence as indicated by Biles et al. (1992), the frequency of alternate row irrigation should be considered to prevent crop water stress. Limiting the frequency or duration of furrow irrigation and preventing plants from undergoing water stress still remains an interesting issue. Profit and cost of the drip system still needs to be evaluated when chile growers anticipate controlling the disease by using drip irrigation.
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