Influence of Irrigation on Severity of Potato Early Dying and Tuber Yield

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ABSTRACT

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The effects of three different irrigation regimes on potato early dying and associated yield loss were assessed in potato cultivar Russet Burbank grown in field microplots at two environmentally distinct locations in Oregon. Fumigated soil was either noninfested or infested with 5, 10, or 25 colony-forming units of *Verticillium dahliae* per gram of soil (cfu). Microplots were drip-irrigated to provide deficit, moderate, or excessive amounts of irrigation water. Moderate irrigation was approximately equal to estimated consumptive use (ECU); the deficit and excessive regimes were 50 and 150% of ECU in 1987 and 50 and 200% of ECU in 1988, respectively. Severity of potato early dying was greater throughout each season when plants grown in infested soil were irrigated excessively compared to those receiving deficit irrigation. An increase in inoculum density under excessive irrigation significantly suppressed tuber yield. Tuber yield was suppressed ($P = 0.05$) by 14, 33, and 30% in soil infested with 25 cfu of *V. dahliae* per gram of soil as compared with noninfested soil at a cool, short-season site in 1988 and a warm, long-season site in 1987 and 1988, respectively. In contrast, under deficit irrigation, an increase in inoculum density had little effect on tuber yield in Umatilla County and there was a slight increase in tuber yield in Crook County. Nitrate-nitrogen concentrations in petioles were significantly lower with excessive compared to deficit irrigation at both locations in 1988. Petiole nitrate-nitrogen concentrations at the warm, long-season site were higher ($P = 0.05$) for plants grown in soil infested with 25 cfu per gram of soil (2.0%) than for plants grown in noninfested soil (1.7%). Increased disease severity under excessive irrigation was not related to nitrogen deficiency, because all petiole nitrate-nitrogen concentrations exceeded critical levels.

Additional keywords: plant nutrient status, soil fertility, soil moisture, *Solanum tuberosum*.

Early dying is a threat to potato (*Solanum tuberosum* L.) production in many areas of the United States and seriously limits the yield of irrigated potatoes in the Pacific Northwest. Although potato early dying can be caused by a complex of interacting pathogens, the soilborne, fungal pathogen *Verticillium dahliae* Kleb. is the major contributor to the disease (2,24,28).

Severity of potato early dying and associated yield loss are influenced by seasonal temperature (13,25) as well as management factors such as irrigation and fertilization (4,5). Temperature has been the most widely studied environmental factor that influences the disease (10,13,21,25); potato early dying is more severe in warm than in cool growing seasons or regions. In contrast, reports on the effect of soil moisture on the development of potato early dying are sparse, and reports on Verticillium wilt in other crops conflict. Studies on cotton and guayule indicate that increased soil moisture increases disease development (7,26), while studies on maple and mint show Verticillum wilt to be more severe under mositure-stress conditions (3,19). Previous studies on Verticillium wilt (potato early dying) suggest that the syndrome is more severe under wet soil conditions. In Idaho, for example, potato early dying occurred earlier and symptoms were more severe during a growing season with wet soil conditions than in a dry season (16), and disease incidence was greater when wilting-point stress on the crop was delayed until mid-August than when moisture stress was applied in late June (5).

Although wet soil conditions increased the severity of Verticillium wilt afflicting other crops (7,26), quantitative data are lacking on the effects of irrigation- or soil-water status on the severity of potato early dying and associated yield loss. Our objectives were to evaluate the effects of deficit-, moderate-, and excessive-irrigation regimes on potato early dying and associated yield loss.

MATERIALS AND METHODS

Field plots. Microplots were established in 1987 and 1988 at the Hermiston Agricultural Research and Extension Center, Umatilla County, in north-central Oregon (192 m elevation; 150-day growing season; Quincy fine sandy loam; mixed, mesic Xeric Torripsamment) and in 1988 at the Central Oregon Experiment Station, Crook County (941 m elevation; 90- to 100-day growing season; Deschutes sandy loam; coarse-loamy, mixed, mesic Xerollic Camborthid). Treatments consisted of one of three irrigation regimes and three or four inoculum densities of *V. dahliae*. At Umatilla County, 1987, and at Crook County, 1988, the factorial combination of treatments was replicated 15 times and arranged in a randomized complete-block design. At Umatilla County, 1988, treatments were arranged in a split-plot design, with irrigation regimes as main plots, arranged in a randomized complete-block design with three blocks and inoculum densities as subplots. Each subplot had five replications of each inoculum density arranged in a completely randomized design.

Inoculum production. Inoculum of *V. dahliae* consisted of a combination of three pathogenic isolates obtained from symptomatic potato plants collected in Umatilla County in 1986. Microsclerotia of each isolate were produced on modified, minimal agar (22) overlain with sterile, uncoated cellophane. After growing for 3 wk at 22–24 C, microsclerotia were harvested by peeling the cellophane from the agar surface. Harvested microsclerotia were blended in sterile water for 2 min and washed several times on a 38-μm sieve. A 10-l twin-shell blender was used to mix quantities of concentrated propagules with pasteurized sand. After mixing the inoculum and sand, 30 0.1 g subsamples of infested sand were assayed for inoculum density of *V. dahliae* (14).

Plot establishment. During October 1986 and 1987, soil at each location was fumigated with methyl bromide/chloropicrin (3:2, v/v) at 488 kg per hectare to reduce other pathogens.

Fumigant was injected at a depth of 20 cm under a 2.1-m-wide continuous plastic tarpaulin. Tarpaulins remained in place throughout the winter and were removed 1 mo before planting the crop. The top 15–20 cm of fumigated soil was scraped to a corner of the plot area and stockpiled for 24 h. Pasteurized sand infested with *V. dahliae* was added to the fumigated field soil and mixed for 3 min in a 0.7-m^3 cement mixer. At Crook County in 1988, a basal application of a 16-16-16-2.7(S) fertilizer provided 168 kg of N, 72 kg of P, 138 kg of K, and 28 kg of S per hectare. At Umatilla County in 1987, each microplot was fertilized at planting with 9-12-6-8(S) to provide 132 kg of N, 74 kg of P, 72 kg of K, and 118 kg of S per hectare. Fertilizer was added to the cement mixer while the soil and inoculum were mixed. Soil tests indicated that basal applications of N, P, K, and S were not required at Umatilla County in 1988. Cylindrical plastic pots (23-l, 40 cm high × 30 cm inside diameter) with a hole 10 cm in diameter bored in the bottom were filled with infested or noninfested soil and placed upright in rows to a depth of 36 cm. Pots were placed 61 cm apart in rows on 172 cm centers.

Nuclear seed potatoes of cultivar Russet Burbank from the Oregon Foundation Seed Potato Program were cut into single-eye seed pieces with a 2.5-cm melon scoop and presprouted for 2 wk in a crisper lined with moist paper towels. A presprouted seed piece was planted 8-cm deep in the center of each pot during the third week of April, the second week of May, and the third week of May at Umatilla (1987 and 1988) and Crook counties (1988), respectively.

Microplots were drip-irrigated to provide deficit, moderate, or excessive amounts of irrigation water. Irrigation treatments were designed so the moderate level was approximately equal to the estimated consumptive use (ECU) of water by the potato crop (i.e., plants were watered as needed). Deficit- and excessive-irrigation treatments were designed to approximate 50 and 150% of ECU in 1987 and 50 and 200% of ECU in 1988, respectively. These levels were achieved by altering the amount of applied water relative to the moderate level; midseason ECU values can exceed 1 cm. During midseason, plants in the moderate treatment were watered daily and plants in the deficit or excessive treatment were watered every other day or twice per day, respectively. For the remainder of the season, microplots were irrigated at 1- to 3-day intervals to maintain the desired irrigation regime throughout the season. At the conclusion of the season, consumptive use (CU) was estimated by multiplying evapotranspiration (Et) by basal crop coefficients for potato (29). Evapotranspiration at Umatilla County in 1987 and 1988 was calculated by the Penman equation (12). At Crook County, in 1988, pan-evaporation data were unavailable, so Et was calculated with maximum and minimum temperatures using the Hargreaves method (12). Cumulative net water status (irrigation + rainfall − ECU) for each irrigation regime is illustrated in Figure 1.

During the 1987 growing season, a urea-ammonium-nitrate solution (32-0-0) was injected into the irrigation system at 2-wk intervals beginning 19 June. This provided 66–131 kg of N per hectare per application for a total of 236–467 kg of N per hectare. Different rates of nitrogen within the experiment at Umatilla County, 1987, were a function of different amounts of applied water. In 1988, the nitrogen solution was applied with a syringe to the soil surface directly beneath the drip emitter in each microplot. The nitrogen solution was injected at a rate of 67 kg of N per hectare per application beginning at tuber initiation for a total of 268 kg of N per hectare at Umatilla County (four applications) and 134 kg of N per hectare at Crook County (two applications). Microplots were irrigated immediately after fertilization to simulate application of nitrogen through irrigation water.

Assays. Beginning in early July, plants were rated weekly for disease severity (percentage of plant with senescent tissue) using the Horsfall-Barratt rating system (11). At tuber initiation and again at tuber bulking, in 1988, four petioles from fully expanded leaves (i.e., the fourth or fifth leaf from the top of the plant) were sampled from each microplot. Because of the small sample size, petioles from replicates 1–5, 6–10, and 11–15 were bulked to form three replicate samples; each consisted of 20 petioles for each irrigation regime-inoculum density treatment combination. Three petioles were collected from each of 12 symptomless plants and from 12 plants with a disease severity rating of 75% or greater in both the deficit- and excessive-irrigation regimes. Petiole samples were analyzed for nitrate nitrogen as well as total phosphorus and potassium by the Plant Analysis Laboratory, Department of Crop and Soil Science, Oregon State University. Interpretation of nutrient concentrations in petioles was based on critical nutrient ranges established for potatoes in the Pacific

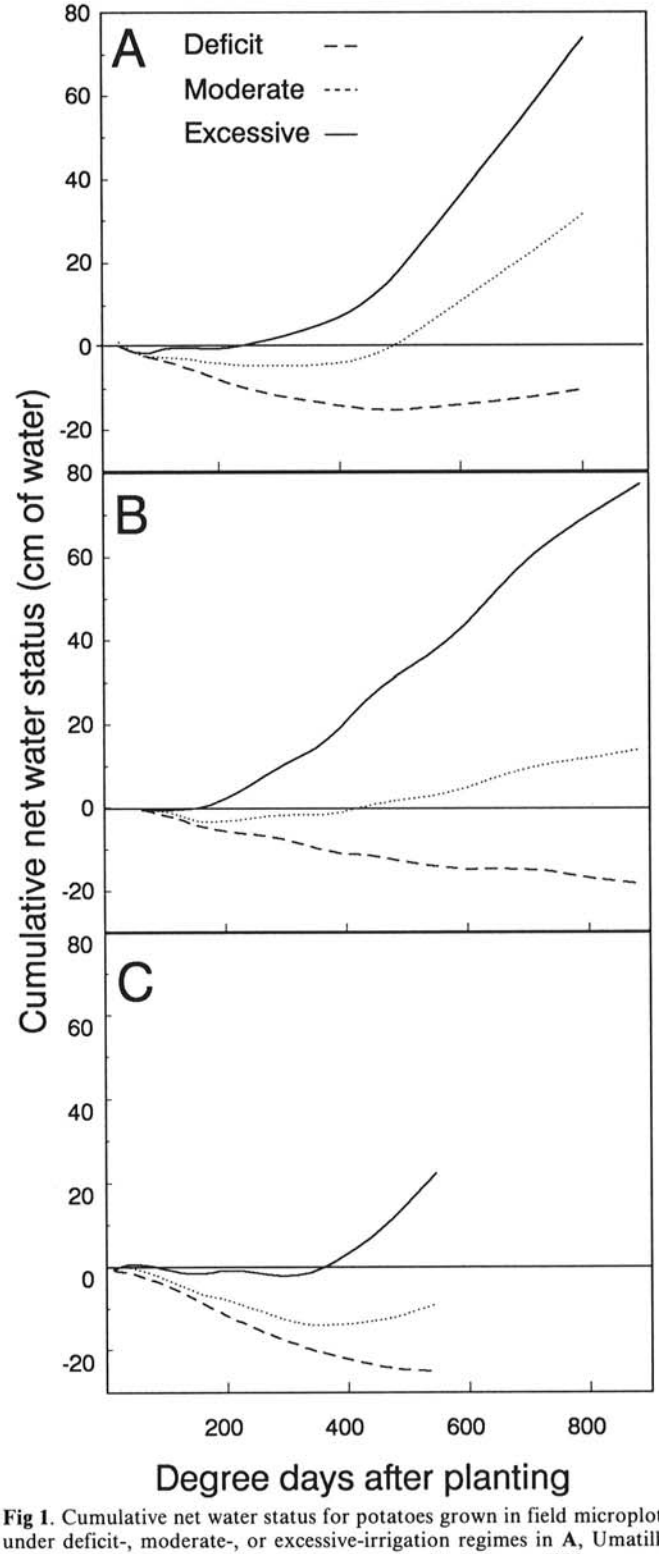

Fig 1. Cumulative net water status for potatoes grown in field microplots under deficit-, moderate-, or excessive-irrigation regimes in **A**, Umatilla County, 1987, seasonal ECU = 57 cm; **B**, Umatilla County, 1988, seasonal ECU = 53 cm; and **C**, Crook County, 1988, seasonal ECU = 52 cm.

Northwest (6). In September, microplots were lifted by hand, and the fresh weight of tubers from each microplot was determined.

Analyses. Responses of area under the senescence progress curve (AUSPC) (27), tuber yield, date of disease onset, and petiole nutrient concentrations underwent an analysis of variance. Degree days after planting (DDAP, base = 12.8 C [55 F]) were calculated by the methods of Baskerville and Emin (1). For AUSPC and tuber yield, main-effect and interaction sums-of-squares were partitioned into linear, quadratic (Umatilla County, 1988, only), and lack-of-fit components (Table 1). For the years with a randomized complete-block design (RCBD) (Umatilla County, 1987, and Crook County, 1988), all observations were used in the analysis (n = 135). For Umatilla County, 1988, a standard

TABLE 1. Sums of squares[a] from analyses of variance for effects of irrigation regime and inoculum density of *Verticillium dahliae* on area under the senescence progress curve (AUSPC) and tuber yield for Russet Burbank potatoes grown in fumigated soil in Oregon field microplots in Umatilla County, 1987, Umatilla County, 1988, and Crook County, 1988

Source	df	AUSPC ($\times 10^6$)	Yield ($\times 10^6$)
		Umatilla County 1987	
Rep	14	622.6106	2.5103
Moisture	2	120.9645	4.0860
ML[b]	1	120.9381	3.4979
MLOF	1	0.0264	0.5881
Inoculum	2	563.8334**	0.5687
IL	1	471.4717**	0.5361
ILOF	1	93.3671	0.0326
Moisture × Inoculum	4	335.4267	2.1750**
ML × IL	1	279.5252*	2.0550**
ML × ILOF	1	5.3667	0.0098
MLOF × IL	1	1.0787	0.0022
MLOF × ILOF	1	49.4562	0.1079
Error	112	4,574.4329	11.5682
		Umatilla County 1988	
Block	2	26.5669*	0.1497
Moisture	2	0.5565	0.8844**
ML	1	0.2662	0.7710
MLOF	1	0.2903	0.7208
Error (a)	4	8.0425	0.0323
Inoculum	3	216.8058**	0.2861**
IL	1	170.4935**	0.1814**
IQ	1	40.0470**	0.3926**
ILOF	1	6.2653	0.0001
Moisture × Inoculum	6	9.0236	0.1777*
ML × IL	1	5.5993	0.0825*
ML × IQ	1	0.5228	0.0879
ML × ILOF	1	1.9701	0.0000
MLOF × IL	1	0.5509	0.0005
MLOF × IQ	1	0.0004	0.0030
MLOF × ILOF	1	0.3802	0.0038
Error (b)	18	23.3202	0.1109
		Crook County 1988	
Rep	14	10.7336	3.0048
Moisture	2	21.5211**	0.5035
ML	1	17.9885**	0.1640
MLOF	1	3.5326*	0.3395
Inoculum	2	104.4873**	0.3422
IL	1	84.3729**	0.0593
ILOF	1	20.1144**	0.2828
Moisture × Inoculum	4	12.6690**	2.9874
ML × IL	1	3.6617*	0.6222
ML × ILOF	1	6.2257**	1.3653
MLOF × IL	1	2.6766	0.7559
MLOF × ILOF	1	0.1049	0.2439
Error	112	88.1324	21.2669

[a] Symbol * or ** indicates that the probability of obtaining a larger F value is less than 0.05 or 0.01, respectively.

[b] Component abbreviations: moisture linear (ML), moisture lack-of-fit (MLOF), inoculum linear (IL), inoculum lack-of-fit (ILOF), and inoculum quadratic (IQ).

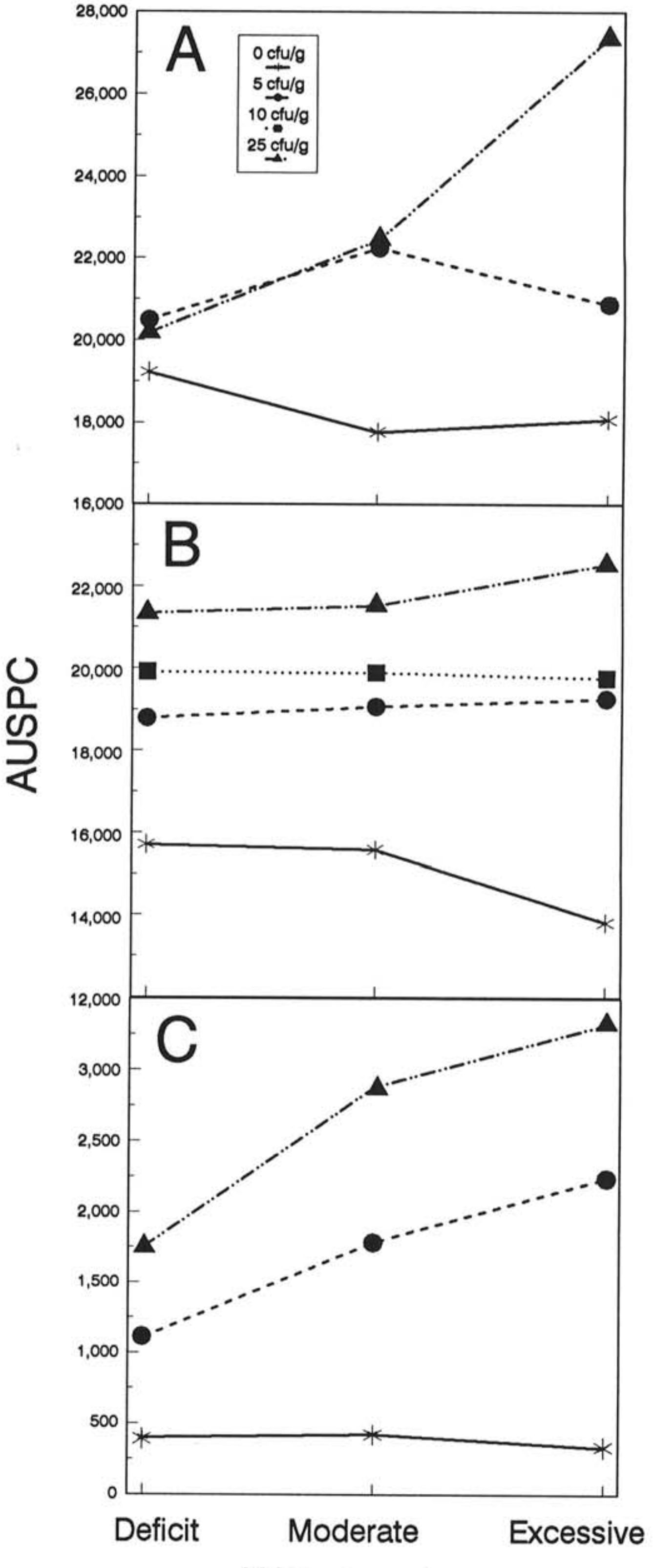

Fig 2. Effects of inoculum density of *Verticillium dahliae* and irrigation regime on mean area under the senescence progress curve (AUSPC) of potato cultivar Russet Burbank grown in fumigated soil in Oregon field microplots in **A**, Umatilla County, 1987; **B**, Umatilla County, 1988; and **C**, Crook County, 1988. Treatments are irrigation regime and inoculum density.

split-plot design was done on the averages over replications within subplots ($n = 36$). When there were significant interactions, two degree-of-freedom contrasts were completed for simple effects within one level of each variable.

RESULTS

Disease severity. Onset of potato early dying occurred between 400 and 500 DDAP. Mean disease onset occurred 31, 14, and 16 DDAP earlier in the excessive-irrigation compared to the deficit-irrigation treatment at Umatilla County (1987 and 1988) and Crook County (1988), respectively. In soil infested with 25 cfu of *V. dahliae* per gram of soil, this response was consistent across locations and years despite the range in total amount of applied water. Seasonal totals for the excessive-irrigation treatment varied from 93 cm of water applied at Crook County during 1988 to 134 cm of water applied at Umatilla County during 1987.

There was a highly significant ($P = 0.01$) main effect of inoculum density at all three locations. This response was predominantly seen in the linear components (IL), although in 1988 the quadratic and lack-of-fit components (IQ and ILOF, respectively) also were highly significant (Table 1). Disease severity, as measured by AUSPC, was significantly influenced by an interaction between irrigation regime and inoculum density at two of the three locations. In Umatilla County, 1987, there was a significant ($P = 0.05$) linear by linear component for the moisture × inoculum interaction. This reflects the fact that only within the highest moisture regime did the mean AUSPC increase markedly; this increase occurred between 5 and 25 cfu per gram of soil (i.e., an effect of water was only seen at the highest level of inoculum) (Fig. 2A). Two degree-of-freedom contrast statements, which compared the change in inoculum effect at a given moisture level, showed that the significant differences occurred only within the excessive-moisture level. Corresponding *P* values for the contrasts of inoculum effect within moisture level were 0.32, 0.37, and 0.00 for the deficit-, moderate-, and excessive-moisture regimes, respectively. At Umatilla County, 1988, there was no effect of moisture on AUSPC (Fig. 2B). At Crook County, 1988, there was a highly significant moisture × inoculum interaction. The linear component of the moisture (ML) was significant in combination with both the IL and ILOF components (Table 1). As the density of inoculum was increased, disease was more severe under excessive compared to deficit or moderate amounts of applied water (Fig. 2C). The contrast statements revealed there was a highly significant response to inoculum density in all three moisture regimes, with corresponding *P* values of 0.00, 0.00, and 0.00 for the inoculum effect within deficit-, moderate-, and excessive-moisture levels, respectively.

Tuber yield. Tuber yield was significantly influenced by an interaction between irrigation regime and inoculum density in all three experiments (Fig. 3). As the amount of inoculum was increased, the proportional suppression in tuber yield was greater when potatoes were grown under an excessive-irrigation regime than when potatoes were grown under a deficit- or moderate-irrigation regime. In Umatilla County, 1987, there was a highly significant linear × linear interaction (Table 1). Although there was no effect of inoculum under deficit irrigation, under excessive irrigation, yields were reduced ($P = 0.00$) 32% when soil infested with 25 cfu per gram was compared to the noninfested control. There was a similar linear × linear interaction in Umatilla County in 1988. Whereas yields increased at all inoculum densities when the deficit-moisture was compared to the excessive-moisture regime, there was a significant yield reduction when soil infested with 25 cfu per gram was compared to the noninfested control at the excessive-moisture level. The effect of inoculum was most pronounced at the excessive-moisture level (Fig. 3B). In contrast to Umatilla County, in Crook County, yields were suppressed at all three inoculum densities as applied water increased from moderate to excessive (Fig. 3C). In the excessive-water regime, yields were suppressed 19% when in noninfested soil compared to soil infested with 25 cfu per gram. When the same comparison

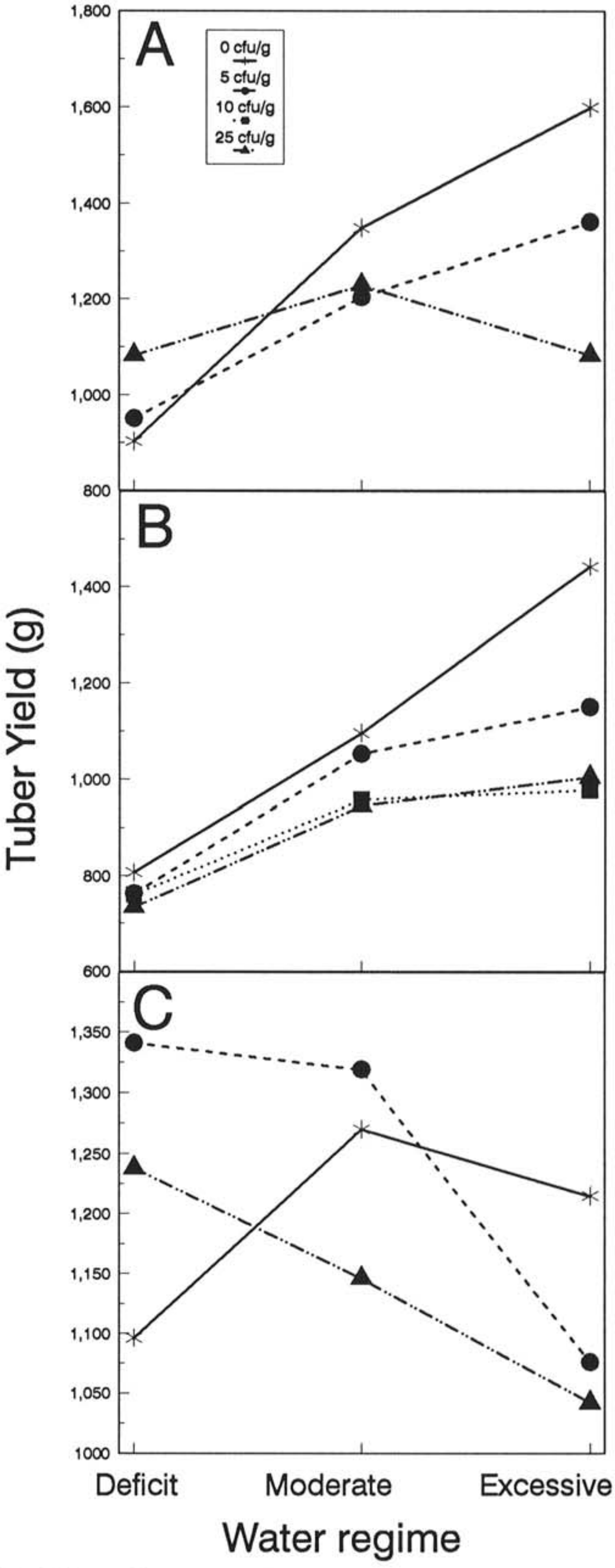

Fig 3. Effects of inoculum density of *Verticillium dahliae* and irrigation regime on mean tuber yield, in grams, of potato cultivar Russet Burbank grown in fumigated soil in Oregon field microplots in **A**, Umatilla County, 1987; **B**, Umatilla County, 1988; and **C**, Crook County, 1988. Treatments are irrigation regime and inoculum density.

was made with the deficit-water regime, tuber yield increased 24%. There is some evidence that yield can be increased by increasing the amount of applied water, however, when potato early dying is present, it may limit any yield increase stemming from additional water.

Petiole nutrient concentrations. Nitrate-nitrogen concentrations in petioles sampled in 1988 at tuber initiation (156 and 373 DDAP at Crook and Umatilla counties, respectively) were influenced by irrigation regime at both locations but were not affected by inoculum density. As the amount of applied water increased from deficit to excessive, corresponding petiole NO_3—N concentrations went from 2.11 to 1.87% and from 1.99 to 1.74% at Crook and Umatilla counties, respectively. Petiole NO_3—N concentrations at tuber bulking (422 and 677 DDAP at Crook and Umatilla counties, respectively) also declined with an increase in the amount of applied water (Table 2). Petiole NO_3—N concentrations were highest ($P = 0.05$) in plants grown in soil infested with a high rate of inoculum at Umatilla County, the site at which disease severity was greatest. Petiole NO_3—N concentrations in plants with and without symptoms at Umatilla County were influenced by a significant interaction between disease severity and irrigation regime. In symptomless plants, petiole NO_3—N concentrations went from 2.09 to 1.33% as the amount of applied water increased from deficit to excessive. Applying excessive water had a smaller effect on petiole NO_3—N concentrations in diseased plants than in symptomless plants. In symptomless plants, concentrations associated with deficit and excessive irrigation were 2.05 and 1.73%, respectively.

Mean concentrations of P and K in petioles from Umatilla County were high at tuber initiation (0.51% P, 9.63% K) and tuber bulking (0.55% P, 8.72% K) and generally were not affected by irrigation or inoculum density. Similar P and K responses were observed at Crook County (data not shown).

DISCUSSION

Potatoes are produced in geographically and environmentally distinct regions in Oregon. Commercial potatoes are grown primarily in the Columbia Basin (Umatilla County), which is characterized by warm temperatures and a long growing season. Both seed and commercial potatoes are produced in Crook County, which has cooler temperatures and a shorter growing season than Umatilla County. Potato early dying occurs at both locations, but disease is always more severe in Umatilla County than in Crook County. In our studies, disease was nearly three times as severe in Umatilla County as in Crook County, during 1988. Mean air temperatures during the growing season were 19.6 and 15.6 C in Umatilla and Crook counties, respectively. Increased disease severity and associated tuber-yield reductions have been correlated with warmer seasonal air temperatures (13,21,25). Despite the environmental differences between these locations, the effect of irrigation regime on disease severity and tuber yield was consistent. Nevertheless, application of excessive amounts of water as a means of alleviating some of the effects of the disease may not be warranted. Soils beneath dying plants remain wet for long periods of time, and wet soil may lead indirectly to tuber-disease problems. An increase in tuber water potential from -0.8 to -0.67 MPa dramatically increased lenticel swelling and the susceptibility of tubers to infection by soft-rot erwinias (15).

TABLE 2. Effects of inoculum densities of *Verticillium dahliae* and irrigation regime on petiole NO_3-N concentrations in potato cultivar Russet Burbank grown in fumigated soil in field microplots at two locations in Oregon in 1988

	NO_3-N concentration (%)[a]	
	Umatilla County	Crook County
Irrigation regime[b]		
Deficit (50% ECU)	2.01 x[c]	1.48 x
Moderate (100% ECU)	1.75 y	1.38 xy
Excessive (200% ECU)	1.49 z	1.28 y
V. dahliae[d]		
0	1.66 x	1.38 x
5	1.63 x	1.34 x
10	1.70 x	...[e]
25	2.01 y	1.42 x

[a] Each value represents mean NO_3-N concentration in 15-petiole composite samples collected on 3 August (677 degree days) in Umatilla County and on 8 August (422 degree days) in Crook County.

[b] Relative amounts of water applied to individual microplots by drip-irrigation, where treatments are a percentage of season-long estimated consumptive use (ECU).

[c] Means within irrigation regimes or inoculum densities followed by the same letter do not differ significantly ($P = 0.05$) using Fisher's protected least significant difference test.

[d] Population levels of *V. dahliae* (colony-forming units per gram of soil) added to soil at planting.

[e] Inoculum density not included.

Increased disease incidence under wet soil conditions has been reported for other soilborne pathogens. Under field conditions, Ferrin and Mitchell (9) demonstrated a clear relationship between increased plant mortality from tobacco black shank and periods of increased soil water. Phytophthora root rot of processing tomatoes developed more rapidly and symptom severity was significantly greater on roots of plants that received prolonged irrigations compared to plants irrigated less frequently (18).

Leaching of nitrate nitrogen from the soil profile due to excessive irrigation has been suggested as one explanation for the increased incidence of disease under wet soil conditions (4). In our studies, nutrient concentrations in the petioles at tuber bulking were influenced by both the amount of applied water and the inoculum density. At both locations, NO_3—N concentrations in petioles were reduced by excessive irrigation. All petiole concentrations, however, were within or above the recognized critical-nutrient ranges for Russet Burbank potato. Therefore, increased disease severity under the excessive-irrigation regime probably was not related to a nitrogen deficiency. In fact, petiole NO_3—N levels were higher in diseased plants than in symptomless plants. The effect of inoculum density on petiole NO_3—N concentration is probably a concentration effect resulting from differences in vine growth; shortening of internodes with the effect of stunting is one symptom of Verticillium wilt.

Other factors, however, may influence the relationship between severity of potato early dying and irrigation regime. Microsclerotia of *V. dahliae* multiplied by sporulation when soil was air-dried and remoistened (8,17). Under irrigation conditions, microsclerotia of *V. dahliae* may sporulate several times, causing an increase in the population density of the pathogen. A study in Wisconsin showed that an increase in soil inoculum density of *V. dahliae* was associated with an increased probability of isolating the fungus from stems of Russet Burbank potatoes earlier in the season (20). An increase in irrigation frequency also can lead to improved root growth throughout the soil profile (23), which may increase the probability of contact with and infection by *V. dahliae*. In short, conditions that enhance the rate of infection will lead to early disease development and will have a major impact on yield.

Many irrigation scheduling programs are based solely on estimates of crop water use. In this study, we used crop-water parameters to estimate the water treatments at the conclusion of the season. Although cumulative net water status for the moderate treatment was not equal to zero throughout the season in all three experiments, we did achieve a separation of irrigation regimes. Seasonal totals of the amount of water applied in the moderate-irrigation treatment were within the range of normal grower practices for all locations. We found that potato early dying could be suppressed by decreasing the amount of applied water. Studies to evaluate the mechanisms of this effect (i.e., the timing of plant infection and plant-growth parameters with respect to soil-water status [matric potential]) are continuing.

Rainfall is rare during the summer months in the Pacific Northwest; as a result, irrigation is essential for optimal potato yields in this region. Although growers optimize yield through irrigation on fumigated ground, improved irrigation scheduling and management are needed to suppress disease on soils infested with *V. dahliae*. In irrigated regions, the amount of applied water can be manipulated by both frequency and duration of irrigation to reduce potato early dying and associated yield loss. High soil-water content early in the season may be critical to the onset of infection of potato plants, whereas water stress on plants after infection may enhance symptom expression. Soil-water content must remain optimal after tuberization to prevent tuber malformation; water management before tuberization, however, may be a viable strategy to manage potato early dying. Studies examining the feasibility of this strategy are currently under way.

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