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Effect of irrigation regimes on disease expression in melon plants infected with *Monosporascus cannonballus*

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Abstract

The effect of irrigation regimes on disease expression in melon plants infected with *Monosporascus cannonballus* was studied during two summer growing seasons (1998 and 1999) in the Arava region of southern Israel. Less frequent and reduced irrigation postponed the onset of plant collapse and lowered disease incidence. Delaying disease development in infested fields by reducing irrigation frequency allowed crop harvest before plant collapse. However, reduced irrigation regimes reduced yields, as shown in methyl bromide fumigated plots. Fruits from melon plants grown under reduced irrigation in the infested plots were also of lower quality due to water shortage. The delay in plant collapse under the reduced irrigation treatments was attributed to a combined effect of reduced fruit load and the development of a deeper root system, which could support the increased water demand of the mature, fruiting plant.

Introduction

Monosporascus cannonballus is the causal agent of a destructive disease of melon (*Cucumis melo*) in the Arava rift region of southern Israel (Pivonia et al., 1997; Cohen et al., 2000). This pathogen is known worldwide and is common in warm, semiarid regions where melon is grown (Martyn and Miller, 1996).

Melon cultivars differ in their response to infection by *M. cannonballus*. Ananas and Honey Dew-type melon cultivars tested in the US were more tolerant to the disease than the American shipper's muskmelons (Wolff and Miller, 1998). The higher tolerance of the Ananas-type melons has been attributed in part to its larger and more vigorous root system, or adaptation to dry-land cropping (Crosby and Wolff, 1998).

Desert agriculture is highly dependent upon drip irrigation. Usually, plant roots that develop under high-frequency drip irrigation are shallow and dense. As a result, plants become sensitive to temporal fluctuations in water availability, temperature and salinity (Shani et al., 1995). Commercial fields of melon in the Arava region are drip-irrigated daily for maximum yield. In this region, wilting symptoms and plant collapse due to *M. cannonballus* infection increase toward the end of the growing season, when plants have a large leaf area and a large number of fruits (Cohen et al., 1996). It has been suggested that, at this stage, a small and diseased root system cannot support the increased plant water demand, thus leading to plant collapse (Crosby and Wolff, 1998). However, the size and structure of the root system can be manipulated by the irrigation regime. Moreover, the timing, frequency, amount and mode of irrigation may affect both root physiological responses (Randall and Locascio, 1988) and sensitivity to pathogenic agents (Palti and Katan, 1997), thus altering disease incidence and severity. The purpose of this work was to study the effect of different irrigation regimes, based on less frequent schedules, on the incidence of melon collapse and on yield and fruit quality in fields infested with *M. cannonballus.*

Materials and methods

The effect of irrigation regimes on the incidence of melon collapse was studied in two field experiments at the 'Yair' Research Station in the Arava region, of southern Israel. Experiments were conducted with the Galia-type melon cv. Revigal (Hazera, Israel). Soil type was a sandy loam soil composed of 80% sand, 10% silt and 10% clay. All experiments were surface drip-irrigated (Netaphim, Israel 2.3 l/h). Inter-row spacing was 40 cm and beds were 150 cm apart. The amount of water applied to various treatments was according to pan evaporation. The daily pan evaporation during July–August in the experiment site ranges 13–15 mms. In the first experiment, two irrigation regimes differing in frequency and amount of watering were tested, as described in Table 1. The irrigation treatments were applied to transplanted and direct sown melons in a *M. cannonballus* naturally infested soils. Planting date was July 16, 1998. Seeds for experiment 2 were direct sown on July 26, 1999. It consisted of four irrigation regimes as described in Table 2. In order to examine the effect of irrigation on melon yield without disease pressure, the high and low irrigation levels were applied as well in a methyl bromide fumigated plots. Methyl bromide was applied 2 weeks before planting as hot gas through the drip system at a rate of 50 g/m^2, for reducing inoculum density. In both experiments, irrigation treatments were arranged in a randomized complete block design with four replicates (plots) per treatment. Each plot was 15 m long, with 30 plants.

Disease, expressed as wilt incidence was evaluated visually in the two experiments. A plant was considered dead when the canopy exhibited irreversible wilt symptoms and collapsed. Wilt incidence (% wilted plants) was evaluated every 5–10 days according to disease development rate. Fruits were harvested twice a week, upon ripening. Fruits in each plot were counted, weighed and sorted for size and quality. As the quality of Galia type melons is correlated with skin netting, quality assessment was based on netting index (0 – smooth, 5 – fully netted) of the fruits. A fruit in which 80–100% of the skin was netted was considered as marketable.

In the 1999, five soil cores were sampled from each irrigation treatment to evaluate the depth of root penetration. The soil samples were taken 85 days after sowing, by the end of fruit harvest, using an aluminum pipe, 5 cm in diameter that was inserted to a depth of 40 cm, adjacent to the main root of living plants. Soil cores were divided into 0–20 cm and 20–40 cm depth sections. Roots were gently washed and separated from the soil, blotted on a filter paper and weighed.

The presence of *M. cannonballus* on the root system of wilting plants, which is considered as an indicator of its involvement in plant collapse, was assessed in all treatments in both years. A quantitative evaluation of root colonization by *M. cannonballus* was carried out at the fruit netting stage in the 1998 experiment. Root segments of four plants from each treatment were sampled randomly. Twelve pieces of secondary roots (0.5–1 cm long) from each root system were plated on potato dextrose agar. Colonization percentages of the roots by the pathogen were evaluated microscopically following incubation for 4–7 days at 27 °C.

Table 1. Irrigation treatments in the 1998 experiment conducted in a soil naturally infested with *M. cannonballus* at Yair experiment station, Arava

Irrigation treatment	Irrigation at growth stage			
	Germination to three true leaves 6–15 d.a.s.[1]	Three true leaves 16–22 d.a.s.	Fruit set 23–44 d.a.s.	Fruit set – maturation[4] 45–70 d.a.s.
A-98 (High irrigation)	Daily 50%[2]	Daily 50%	Daily 70%	Twice a day 100%
B-98 (Low irrigation)	Once every 2 days, 30%	No irrigation for 7 days[3]	Once every 2 days, 35%	Daily 35%

[1]Days after sowing or planting. Soil was irrigated daily till germination.
[2]Percentage of pan evaporation.
[3]Plants were given a recovery irrigation of 20% of pan evaporation for each day of irrigation deficiency after irrigation was reinstated.
[4]Irrigation regimes applied till the experiment ended.

Table 2. Irrigation treatments of the 1999 experiment, Yair experiment station, Arava

Treatment	Irrigation application			
	Germination to three true leaves 6–17 d.a.s.[1]	Three true leaves 18–22 d.a.s.	Flowering – fruit set 23–44 d.a.s.	Fruit set – maturation 45–70 d.a.s.[6]
A-99[2] (Low irrigation)	Once every 2 days, 30%[4]	No irrigation for 5 days[5]	Once every 2 days, 40%	Once every 2 days, 50%
B-99[2] (Moderately low irrigation)	Once every 2 days, 30%	No irrigation for 5 days	Daily, 40%	Daily, 50%
C-99[2] (Moderately high irrigation)	Once every 2 days, 30%	No irrigation for 5 days	Daily, 60%	Daily, 80%
D-99[2] (High irrigation)	Once every 2 days, 30%	Daily, 40%	Daily, 60%	Daily, 80%
E-99[3] (High irrigation)	Once every 2 days, 30%	Daily, 40%	Daily, 60%	Daily, 80%
F-99[3] (Low irrigation)	Once every 2 days, 30%	No irrigation for 5 days	Once every 2 days, 40%	Once every 2 days, 50%

[1]Days after sowing. Soil was irrigated daily until germination.
[2]Soil naturally infested with *M. cannonballus.*
[3]Soil fumigated with methyl bromide at 50 g/m^2.
[4]Percentage of pan evaporation.
[5]Plants were given a recovery irrigation of 20% of pan evaporation for each day of irrigation deficiency after irrigation was reinstated.
[6]Irrigation regimes applied till the experiment ended.

Statistical analyses

The data were subjected to one-way analysis of variance using JMP software (SAS Institute Inc.). Disease development was expressed in area under disease progress curve (AUDPC) calculated according to the mid point rule (Campbell and Madden, 1990), units are proportion-days. The Tukey–Kramer honestly significant difference test ($P = 0.05$) was used to compare means.

Results

Effect of irrigation regimes on disease incidence

In the first experiment (1998), the commonly used practice of daily irrigation advanced and accelerated disease progress in melon plants as compared with the reduced irrigation treatment (Figure 1). Disease symptoms in the daily-irrigated regime (A-98) were first observed 46 days after planting and the plants were totally wilted 16 days later, before fruit maturation. In the reduced irrigation treatment (B-98), first

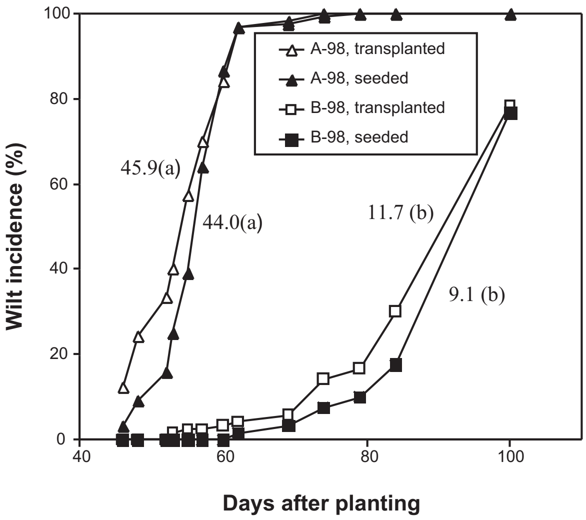

Figure 1. Disease development of directly seeded or transplanted melon plants grown in *M. cannonballus* naturally infested soil as affected by irrigation treatments, summer 1998. A-98: Commonly practiced high-level irrigation; B-98: low irrigation. AUDPC are proportion × days values and are indicated by numbers and those with a common letter are not significantly different at $P \leq 0.05$. Irrigation treatments are described in Table 1.

wilting symptoms occurred later, 70 days after planting. Consequently, the slower progress of the disease enabled harvesting of the crop. Transplanted melon plants tended to show somewhat higher and earlier wilt incidence (by about 5 days) compared with direct seeded plants in the daily-irrigated regime (Figure 1), apparently due an enhanced plant development.

In the second experiment (1999), there was tendency toward increased disease incidence with increased irrigation frequency. The mean AUDPC value for plants grown under high-level irrigation (D-99), was significantly higher than that of the other three irrigation treatments (Figure 2). By the end of the experiment (110 days after planting) the lowest collapse incidence was observed in the A-99 and F-99 treatments, in which the soil was less wetted, in the infested and in the fumigated soils, respectively. Disease progress in the high-level irrigation treatment in the 1999 experiment was slower than in the relative treatment in 1998 experiment. In the 1999 experiment, plants in the high-level irrigation treatment (D-99) were irrigated once every 2 days at the beginning of the season and had lower irrigation throughout the season, compared to the daily irrigation in the 1998 experiment (A-98). The disease

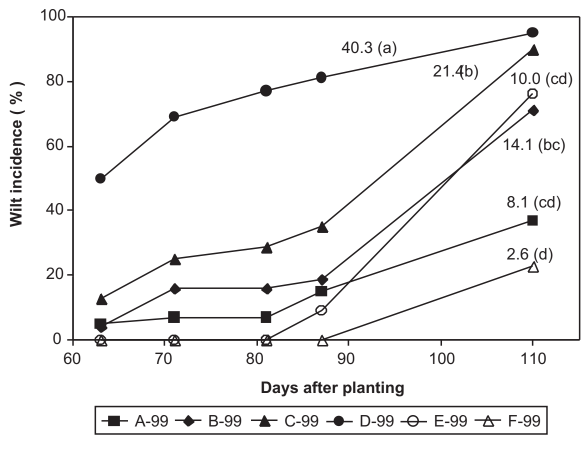

Figure 2. Disease development of directly seeded melon plants grown in *M. cannonballus* naturally infested soil and in methyl bromide fumigated soil, as affected by irrigation treatments, summer 1999. AUDPC are proportion × days values and indicated by numbers and those with a common letter are not significantly different at $P \leq 0.05$. A-99: low irrigation; B-99: moderately low irrigation; C-99: moderately high irrigation; D-99: Commonly practiced high-level irrigation; treatments E-99 and F-99: as treatments D-99 and A-99 with methyl bromide fumigation. Detailed irrigation treatments are described in Table 2. Fruit were harvested between 62 and 82 days after planting.

observed toward the end of the experiment in the treatments that received methyl bromide fumigation (E and F-99), was probably due to unsatisfactory fumigation or reinfestation by the pathogen accrued during the growing season.

Effect of irrigation regimes on melon yield

Reduced irrigation regimes did not affect timing of melon fruit set and maturation. It affected mainly fruit size and fruit load. In general, fruits from the reduced irrigation treatments were smaller and of lower quality as compared to the high-level irrigation treatments.

In 1998, melon plants that were daily irrigated (A-98), collapsed totally before fruit maturation and did not yield any marketable fruits. In the reduced irrigation treatment (B-98), the yields in the sown and transplanted plots were similar, ranging between 1.09 and 1.37 kg/m^2, which is about 30% of the yield commonly obtained in methyl bromide fumigated commercial fields in this region during the same growing season.

In 1999, fruits were harvested 62–82 days after planting, in all treatments. Before the onset of harvest, disease incidence in the reduced irrigation treatments was low, and most fruits were picked before the plants collapsed. In the methyl bromide fumigated soil, the low irrigation frequency treatment (F-99) resulted in a 43% yield reduction as compared with the high-level irrigation treatment (E-99) (Figure 3). This reflects

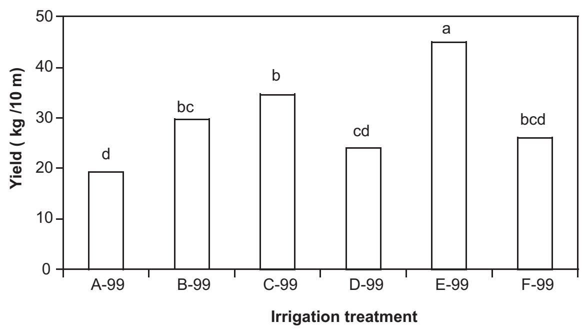

Figure 3. Total yield of directly seeded melon plants grown in *M. cannonballus* naturally infested soil and in methyl bromide fumigated soil, as affected by irrigation treatments, summer1999. Values with the same letter are not significantly different at $P \leq 0.05$. A-99: low irrigation; B-99: moderately low irrigation; C-99: moderately high irrigation; D-99: commonly practiced high-level irrigation; treatments E-99 and F-99: as treatments D-99 and A-99 with methyl bromide fumigation. Detailed irrigation treatments are described in Table 2.

Table 3. Weight of seeded melon roots, at two soil depths, as affected by irrigation treatment, sampled from the 1999 experiment. Values in a column followed by the same letter are not significantly different at $P < 0.05$ using the Tukey–Kramer honestly significant difference test

Irrigation treatment		Soil status	Root fresh weight (g/l soil)		Deep/shallow roots weight ratio
			Shallow (0–20 cm)	Deep (20–40 cm)	
A-99	Low irrigation	Infested[1]	1.30 a	0.51 a	0.39 a
B-99	Moderately low irrigation	Infested	1.78 a	0.28 ab	0.16 abc
C-99	Moderately high irrigation	Infested	1.89 a	0.23 ab	0.12 bc
D-99	High-level irrigation	Infested	1.78 a	0.03 b	0.02 c
E-99	High-level irrigation	Fumigated[2]	1.63 a	0.13 b	0.08 c
F-99	Low irrigation	Fumigated	1.48 a	0.54 a	0.36 ab

[1]Soil naturally infested with *M. cannonballus*.
[2]Soil fumigated with methyl bromide at 50 g/m^2.

a yield loss due to reduced irrigation, which was a combination of lower fruit load and lower fruit weight. Average fruit weight and fruit load were 0.76 kg and 2.1 fruits per plant, respectively in treatment F-99 comparing 0.87 kg and 3.1 fruits per plant in treatment E-99 ($P < 0.05$). In the infested soil, total fruit yield in the low-level irrigation treatment (A-99) did not differ from the yield in the high-level irrigation treatment (D-99). Unlike the 1998 experiment, in which all plants in the daily irrigation treatment collapsed before fruit maturation, the high-level irrigation treatment of 1999 produced 2.4 kg/m^2 total yield. The yields in the moderate irrigation treatments C-99 and B-99 were increased by about 40% ($P < 0.05$) and 20% ($P =$ NS) compared to the high-level irrigation treatment (D-99), and by ca. 75% ($P < 0.05$) and ca. 50% ($P < 0.05$) compared to the treatment with the lowest irrigation (A-99), respectively. Average fruit weight in the infested soil plots was 0.63, 0.67, 0.65 and 0.72 kg ($P =$ NS) in treatments A-99 to D-99, respectively.

Effect of irrigation regimes on root development

In 1998, root distribution in the soil in plants irrigated daily was shallower than the low irrigated treatment. In the daily irrigation treatment, roots reached a depth of 25 cm and the main root system was concentrated in the upper 15 cm soil layer. In the reduced irrigation treatment roots penetrated to a 40 cm depth and were uniformly distributed throughout the soil profile. In the 1999 experiment, root fresh weight in the deeper 20–40 cm soil layer was significantly higher in the A-99 and F-99 low irrigation treatments, than in the high-level irrigation treatments (D-99 and E-99) (Table 3). No differences were observed among the various treatments in root fresh weight in the upper soil layer (0–20 cm). The largest deep/shallow root weight ratio was observed in the two low irrigation treatments (Table 3).

Effect of irrigation regimes on root colonization by M. cannonballus

Monosporascus cannonballus peritechia were observed on the root system of wilting plants in all treatments in both experiments. In 1998, secondary roots sampled from seeded and transplanted plants in both irrigation treatments had similar level of colonization (about 50%) at the onset of fruit netting (50 days after planting).

Discussion

The results demonstrate that reducing the level and the frequency of irrigation throughout the growing season, postponed wilt symptoms in plants infected with *M. cannonballus*. Reducing the irrigation level also affected fruit yield. Earlier studies showed that the appearance of wilt symptoms in melon plants infected with *M. cannonballus* is associated with fruit set and maturation. Fruit removal from plants can prevent their death, while partial fruit removal to produce one fruit per plant can delay symptom appearance. Nonetheless plants may collapse before fruit maturation (Pivonia et al., 1997). In the current study, the delay in symptom appearance was sufficient to enable fruit maturation before the plants collapsed. However, reduced fruit load by itself, could not explain the delay in plant collapse and it was suggested that other mechanisms might be involved. Indeed, reducing the irrigation level in the beginning of and throughout the season enhanced root growth toward deeper soil layers, as compared with plants grown under daily irrigation. The deeper and probably larger root system can better support their future water demand. It is also conceivable that the larger root system will also enable the plants to overcome the water shortage caused by the disease later in the season, at the time of fruit netting and maturation. Prolonging plant life due to reduced irrigation allowed fruit maturation before plant collapse compared to regular irrigation. Melon yield in infested fields, increased under reduced irrigation due to the delay in plant collapse, but was lower in quantity and quality due to water shortage. The long-term goal of an appropriate irrigation management regime would be to find an optimal compromise between these two opposing effects.

The fact that the disease is prevented and the yield can be increased in infested fields by grafting melon plants on *Cucurbita* rootstocks supports the proposed role of a larger root system in postponing *M. cannonballus* collapse in melon (Edelstein et al., 1999). The genus *Cucurbita* is defined as a host of the pathogen (Mertely et al., 1993). However, plant mortality is usually very low and occurs much later in the season in *Cucurbita* plants or in melon grafted on *Cucurbita* rootstocks, as compared to non-grafted melons. The above-ground symptomless nature of this host/pathogen interaction is at least partially due to the large root system that, even if infected by the pathogen, is still able to overcome the expression of wilt symptoms. Recent work on root traits of muskmelon types tolerant to *M. cannonballus* suggested that tolerance can be linked to the integrity of root structure (Crosby et al., 2000). Looking for large root system which may compensate the fungus damage was offered as a breeding strategy to improve vine decline resistance (Dias et al., 2002).

It can be argued that the low disease incidence in the less irrigated treatments was due to their deeper root system, which escaped the pathogen. This is unlikely, since similar levels of *M. cannonballus* root infection were found in roots of plants without any wilt symptoms from the less frequent irrigation and in roots of wilted plants from the daily-irrigated treatment. A study conducted in Arizona showed similar ascospore densities both vertically and horizontally, to the depth of 25 cm (Stanghellini et al., 1996), suggesting that inoculum availability is not a limiting factor in the soil depth range exploited by melon plants.

In a previous study in another locality in the Arava Valley, Reuveni et al. (1983) found that daily irrigation in a *Monosporascus* infested field lowered disease incidence compared with irrigation once in 3 days throughout the whole growing season. These results are apparently in contrast with the present study. However, in the present study, the irrigation quantity and frequency were changed throughout the season according to the plant growth stages. Plant vegetative growth is curtailed by fruit development and fruit load reduced root growth more than shoot growth in cucumber (de Stigter, 1969; Marcelis, 1994) and in melon (El-Keblawy and Lovett-Doust, 1996). Our study suggests that reduced irrigation frequency at the beginning of the season, before the fruiting stage, might delay plant mortality at the fruit maturity stage. At the fruit growth stage, and especially at fruit netting and maturation, irrigation should be given daily to facilitate water uptake via the progressively deteriorating root system infected with *M. cannonballus* (see also, Reuveni et al., 1983).

Although, manipulating irrigation can postpone plant collapse, the risks of a reduction in yield and fruit quality due to water shortage cannot be ignored. Irrigation cannot be used as the sole management practice to control this disease, but perhaps could be a component in an integrated management program. Further studies are needed to optimize the beneficial effects of reduced irrigation and to combine it with other management practices, in order to lower disease incidence while maintaining a commercially acceptable yield.

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