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The effect of irrigation frequency on water and carbon relations in three cultivars of sweet pepper (*Capsicum chinense* Jacq), in a tropical semiarid region

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Abstract

The effect of three irrigation frequencies (3, 6 and 9 days) on water balance, gas exchange and fruit production of three cultivars of *C*. chinense was evaluated in the field with the aim of selecting the cultivars that are most resistant to water deficits, yet have high yields. A split-plot design with three replicates was employed. Available soil water content at the moment of irrigation was 68–80%, 35-45% and 8–20% of field capacity for 3, 6 and 9 days, respectively. Leaf gas exchange and leaf water potential were measured at 2 and 2.5 hour intervals, respectively, 45, 63, 87 and 101 days after transplanting from seed beds. Pressure-volume curves were used to determine osmotic potential at turgor loss. Fruit production was measured from weekly collections throughout the experiment. Early morning and minimum water potentials decreased at lower irrigation frequencies for two of the cultivars. A decrease in osmotic potential at turgor loss (0.25–0.42 MPa) was observed in the same two cultivars, indicating they are capable of adjusting osmotically. A significant reduction in maximum stomatal conductance was observed between plants watered every 3 (139–193 mmolm^{-2} s^{-1}) and 6 days (71–85 mmolm^{-2} s^{-1}). There were no differences between 6 and 9 days. The same trend was obtained for mean daily assimilation (4.7–5.6 μmolm^{-2} s^{-1} for 3 days and 3.0–3.7 μmolm $^{-2}$ s^{-1} for 6 days). Fruit production was affected in different degrees depending on the cultivar (from 24% upto 40% reduction between 3 and 6 day frequencies). © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Water stress; Osmotic adjustment; Crop ecophysiology; *Capsicum chinense*

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1. Introduction

The principal limiting factor for farmers in arid and semi-arid regions is water. Crop land in these areas is restricted by water availability and farmers grow crops that are able to adapt to drought conditions (Muchow, 1989). In some regions this has led to an increase of monocrops that are more resistant to water deficits.

Mechanisms that permit plants to survive in these unfavourable environments vary between species and include: changes in stomatal response; osmotic adjustment; and a greater movement of photosynthates to the roots in order to increase root length for extracting water at greater depths (Horton et al., 1982; Austin, 1989; Blum, 1989a; Castonguay and Markhart, 1992). Other studies have reported that the genus *Capsicum* exhibits similar physiological responses when confronted with a water deficit (Batal and Smittle, 1981; Beese et al., 1982; Hulugalle and Willat, 1987). Experiments have also been conducted where the total quantity of water available to this genus varies, but watering frequency remains the same (Beese et al., 1982; Horton et al., 1982). Results from these studies demonstrated that growth and production were positively correlated with water quantity due to effects on leaf area, however, water potential and stomatal resistance were only slightly affected by low water availability. Most experiments on *Capsicum* have been conducted in controlled glasshouse conditions (Nilwik, 1981; Nielsen and Veierskov, 1988). Field studies on the effect of water deficit on growth, gas exchange and water economy in drought conditions in this genus are few (Horton et al., 1982; Russo, 1983; Hegde, 1987; Wullschleger and Oosterhuis, 1991; Ismail and Davies, 1997). It is important to understand the response of crops to different periods of water deficit in order to determine the watering frequency tolerated by a crop and the reduction of yield tolerated by the farmer.

To our knowledge, the effect of water shortages on the phenology of *C. chinense* Jacq, commonly known as sweet pepper in Venezuela, have not been reported. In this study, the water balance of different cultivars of *C. chinense*, was determined using different watering regimes. The effect of water shortages on gas exchange and fruit production was evaluated in the field with the aim of selecting the cultivars that are most resistant to water deficits. The relationship between irrigation frequency and fruit production was also evaluated.

2. Materials and methods

The study was conducted in the Experimental Station of the Agricultural Institute (IIAP) of the University of the Andes, in San Juan de Lagunillas, State of Mérida (08°31′N, 71°71′W), at an altitude of 1100 m. This is a semi-arid region with a mean annual rainfall of 570 mm, a mean daily evaporation of 5.6 mm and a mean annual temperature of 22°C. Soil type has been classified as Cambortid, with an effective depth of 21 cm (Ochoa and Malagón, 1979).

Three cultivars of *C. chinense* cultivated in this region were selected for this study: AMES1: yellow (Cultivar 1); ANMB1: orange (Cultivar 2); ROOR1: red (Cultivar 3). Seeds of the three cultivars were sown on 30 September 1994 in previously disinfected and exposed seed beds. Preventive methods were utilized to control insect pests and pathogens. Plantlings were transplanted to the field 68 days later (8 December 1994) with 40 cm between plants and 80 cm between rows, following recommendations by Suniaga (1980) and Añez and Figueredo (1993). During the first stage of plant establishment, all plants were watered by irrigation ($12\ l/m^2$) every 2–3 days for 27 days. Treatments with different watering regimes were initiated from the 28th day onward. Plants were watered with $12\ l/m^2$ every 3, 6 or 9 days. Field capacity and permanent wilting point (20 cm in depth) were determined with a ceramic plate extractor at 0.03 and 1.5 MPa, respectively. Available soil water content at 20 cm in depth was measured with resistance blocks. Plants were fertilized 30 days after transplanting (DAT) with 95 Kg/ha of 14–14–14 commerical NPK fertilizer, followed by 23 Kg/ha of N in the form of diammonium phosphate, 45 and 65 DAT; and 200 kg/ha of K as K_2SO_4, 65 DAT. Curacron (profenofos) was applied (0.65 l/ha) on 13 January and 14 February 1996 to control lepidopteran pests.

A split-plot design with three blocks was employed to evaluate water relation parameters and fruit production. Main plots, within each block, were randomly assigned to watering frequency, and the sub-plots randomly assigned to plant cultivar. Measurements were recorded on the last day of the deficit period for each treatment. Early morning water potential (8:00–9:00 hours) and minimum water potential (always occurred between 13:00–14:00 hours) were measured in one mature, upper leaf of three replicate plants chosen at random from each subplot (nine for each watering treatment), at 63 and 87 DAT using a pressure chamber. Pressure-volume curves for four leaves of each subplot (12 for each treatment) (Tyree and Hammel, 1972; Tyree and Richter, 1981) were used to determine osmotic potential at turgor loss on two occasions (63 and 87 DAT). Fruit production was measured at weekly intervals throughout the experiment. Total fresh weight was determined from all collected fruits at the end of the study (160 DAT). Primary data were subjected to the analysis of variance and Duncan's test was applied where appropriate to determine main treatment effects and interactions.

Stomatal conductance and CO_2 assimilation were also measured (63 and 87 DAT) in totally expanded leaves (five plants per treatment randomly selected from all blocks), at two hour intervals, using a portable gas exchange system in an open mode (LCA-2, ADC). Integration of daily CO_2 assimilation curves (from 8:00 until 18:00 hours) were carried out in order to obtain total daily assimilation (A_{tot}) (McCree et al., 1984; Rada et al., 1996).

Table 1

Early morning (Ψ_{em}, MPa) and minimum (Ψ_{min} , MPa.) water potentials, and osmotic potential at zero turgor ($\Psi\pi^0$, MPa.) for three cultivars of *C. chinense* under three irrigation frequencies. Values are means of 63 and 87 DAT

	Irrigation frequency (days)	Ψ_{em}	Ψ_{min}	Ψ_{π}^{0}
Cultivar 1	3	-0.65^{a}	-1.37^{a}	-1.20^{a}
	6	-1.50^{b}	-1.83^{b}	-1.15^{a}
	9	-1.61^{b}	-1.63^{b}	-1.26^{a}
Cultivar 2	3	-0.78^{a}	-1.35^{a}	-1.20^{a}
	6	-1.53^{b}	-1.58^{ab}	-1.45^{b}
	9	-1.64^{b}	-1.78^{b}	-1.41^{b}
Cultivar 3	3	-0.76^{a}	-1.43^{a}	-1.38^{a}
	6	-1.21^{c}	-1.80^{b}	-1.80^{c}
	9	-1.53^{b}	-2.00^{b}	-1.78^{c}

[a,b,c] Mean differences within column according to Duncan's multiple range test at $p < 0.05$.

3. Results

Available soil water content, independent of irrigation frequency, reached field capacity (17%) immediately after watering. Just before watering, available soil water content was 68–80%, 35–45% and 8–20% of field capacity for 3, 6 and 9 day treatments, respectively.

Early morning (Ψ_{em}) and minimum (Ψ_{min}) water potentials were significantly lower with a decrease in irrigation frequency for all cultivars, with the exception of Ψ_{min} for Cultivar 1 where this trend was not observed (Table 1). Osmotic potential at the point of turgor loss ($\Psi\pi^{\circ}$) did not decrease with different watering frequencies in Cultivar 1, indicating that this cultivar is unable to adjust osmotically. A reduction of 0.25 MPa was observed for Cultivar 2 and 0.42 MPa for Cultivar 3, between 3 and 6 days, which indicated that these two cultivars adjusted osmotically to some degree, although this was only significant for Cultivar 3.

A reduction in maximum stomatal conductance was observed in plants watered every 6 days compared to those watered every 3 days for all the cultivars. No variation was found between plants watered every 6 and 9 days (Table 2). As with stomatal conductance, a reduction of mean daily assimilation (A_m) was observed in 6-day in relation to 3-day treatments, while no differences were found between plants watered every 6 and 9 days.

A reduction in total daily assimilation (A_{tot}) was observed in all three cultivars when plants were watered every 6 days rather than every 3 days (Table 3). An additional reduction was not observed between plants watered every 6 and 9 days. In relation to fruit production, a marked reduction was evident in cultivars 1 and 2

Table 2
Effect of irrigation frequency on mean assimilation (A_m, μmolm^{-2} s^{-1}), maximum stomatal conductance (g_s, mmolm^{-2} s^{-1}) and maximum assimilation (A_{max}, μmolm^{-2} s^{-1}) in three varieties of *C. chinense*.). Values are means of 63 and 87 DAT ± standard error

	Irrigation frequency(days)	A_m	g_s	A_{max}
Cultivar 1	3	5.24 ± 2.5	141.9 ± 45.9	8.23 ± 3.13
	6	3.02 ± 2.0	71.2 ± 20.3	3.34 ± 0.70
	9	3.85 ± 2.3	70.7 ± 7.7	5.72 ± 1.00
Cultivar 2	3	4.70 ± 2.1	193.0 ± 56.3	6.66 ± 3.94
	6	3.58 ± 2.4	84.8 ± 12.8	6.59 ± 3.40
	9	3.57 ± 1.7	82.8 ± 11.6	5.20 ± 1.03
Cultivar 3	3	5.57 ± 3.1	139.2 ± 32.8	7.92 ± 4.00
	6	3.66 ± 2.1	72.8 ± 26.7	6.85 ± 3.60
	9	3.78 ± 1.6	55.9 ± 7.2	5.10 ± 0.81

Table 3
Effect of irrigation frequency on total daily assimilation (A_{tot}, molm^{-2}day^{-1}) and fruit production (t/ha) in three varieties of *C. chinense*. Values for A_{tot} are means of 63 and 87 DAT ± standard error

	Irrigation frequency	A_{tot}	Production
Cultivar 1	3	141.22 ± 14.91	15.30 ± 3.74^b
	6	84.81 ± 21.16	9.60 ± 0.44^c
	9	104.15 ± 20.41	10.76 ± 3.16^c
Cultivar 2	3	126.97 ± 19.93	22.50 ± 2.12^a
	6	96.88 ± 34.94	16.73 ± 2.42^b
	9	96.62 ± 40.02	12.12 ± 2.29^c
Cultivar 3	3	150.48 ± 6.23	16.84 ± 2.52^b
	6	98.89 ± 22.55	14.38 ± 1.31^b
	9	102.17 ± 38.16	10.05 ± 2.32^c

[a,b,c] Mean differences within column according to Duncan's multiple range test at $p < 0.05$.

between those watered every 3 and 6 days, but not for Cultivar 3 ($p < 0.05$). Although significant differences were not generally observed for the different gas exchange parameters between plants watered every 6 and 9 days, the effect of water stress was significantly reflected in fruit production for cultivars 2 and 3.

4. Discussion

This study demonstrates that irrigation frequencies of 6 days in environments with a high evaporative demand such as San Juan de Lagunillas result in turgor loss as can be observed from the minimum water potentials in relation to the osmotic potential at turgor loss.

Responses to water stress differed significantly between the cultivars. Osmotic adjustment permitted Cultivar 3 to maintain an important margin between Ψ_{em} and the $\Psi\pi$ for all three treatments and it was able to maintain higher stomatal conductances during the morning (data not shown). On the other hand, little or no adjustment was observed in the other two cultivars which led to the plants being close to or below the point of turgor loss during the early morning hours. Between 13:00 and 14:00 hours, when evaporative demand was highest, leaf water potential in all cultivars was at or below the turgor loss point, including those plants watered every 3 days. Osmotic adjustment under field conditions has been described for several crops and the value obtained in this study (0.42 MPa) is similar to that obtained for barley by Blum (1989b) who observed osmotic adjustments between 0.17 and 0.46 MPa in the laboratory. Other authors also found osmotic adjustment for different cultivars of *Capsicum annuum* (Wullschleger and Oosterhuis, 1991; Ismail and Davies, 1997) and *Capsicum frutescens* (Ismail and Davies, 1997). Results of our study demonstrate that the mechanism of osmoregulation in the cultivars of *C. chinense* does not increase with irrigation frequencies greater than 6 days, indicating that there is a limit to turgor maintenance.

Partial stomatal closure between 3 and 6 day irrigation frequencies for all cultivars corresponds to minimum water potentials between −1.6 and −1.8 MPa. Similar to our results, Horton et al. (1982) showed that stomatal conductance in chile peppers decreased below −1.6 MPa and closure occurred at −1.8 MPa.

The reduction in stomatal conductance, for all cultivars, between 3 and 6 day treatments corresponds to approximately 50%, which appears to affect the assimilation of CO_2 to different degrees in each cultivar. Similar results have been described in *C. annuum* seedlings where stomatal closure was accompanied by a reduction in photosynthetic rates after 48 h without watering (Aloni et al., 1991). The reduction of A_{m} and A_{tot} between 3 and 6 day irrigation frequencies was 40, 24 and 35% for cultivars 1, 2 and 3, respectively. These results indicate that Cultivar 1 is the most affected in terms of assimilation which is reflected in a reduction of approximately 40% of fruit production between plants watered every 3 and 6 days. Cultivar 2 is the least affected in terms of CO_2 assimilation between treatments (24% reduction) exhibiting a similar reduction in fruit production (26%). These results imply that for cultivars 1 and 2 the manufacture of photosynthates directly affects final fruit production. The reduction of CO_2 assimilation (35%) between treatments in Cultivar 3 only reduced fruit production by 15%, suggesting that the reduction in assimilate formation affects biomass or other processes in favor of fruit production.

Observations from this study suggest that the optimum watering frequency for *C. chinense* is every three days. Taking into account water availability in this region, cultivars 2 and 3 should be watered at least every 6 days. This watering frequency would be accompanied by a reduction of 26 and 15% fruit production for these cultivars, respectively; and would save 204 l/m^2 of water from that utilized in plants watered every 3 days. In ecophysiological terms, Cultivar 3 is the best adapted to water stress. This cultivar exhibited significant osmotic adjustment which in turn permitted turgor maintenance and fruit production to be least affected by unfavourable water conditions. However, in terms of total fruit production, Cultivar 2 is superior in all treatments.

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