CHAPTER 3

THE EFFECT OF DIFFERENT IRRIGATION REGIMES ON GROWTH AND YIELD OF THREE HOT PEPPER (*Capsicum annuum* L.) CULTIVARS

Abstract

A field trial was conducted in the 2004/2005 growing season at the Hatfield Experimental Farm (Pretoria) to investigate the effect of different irrigation regimes on the growth, yield and water-use efficiency of different hot pepper cultivars. The aim was to select cultivars that are efficient in water utilization. Treatments were arranged in a randomized complete block strip plot design, with irrigation regime assigned to main plots and cultivars to sub-plots. The three cultivars were Mareko Fana, Jalapeno and Malaga and the three irrigation regimes, based on the percentage depletion of plant available water (DPAW) to 0.6 m soil depth were 25D: 20-25% DPAW; 55D: 50-55% DPAW; and 75D: 70-75% DPAW. Treatments were replicated three times and drip irrigation was utilized. Growth analysis, soil water content and yield measurements were performed.

Fresh fruit yield increased by 77 % and dry fruit yield increased by 64 % by irrigating at 25D as compared to 75D. The significantly higher yield obtained by the 25D irrigation tratment is attributed to its positive effect on fruit number and top dry biomass production. Cultivar Mareko Fana (3.63 t ha^{-1}) out-yielded Jalapeno (3.44 t ha^{-1}) and Malaga (2.11 t ha^{-1}) by 5 and 71 %, respectively in dry fruit yield. Higher fruit fresh yield was recorded for Jalapeno (29.28 t ha^{-1}), followed by Mareko Fana (21.49 t ha^{-1}) and Malaga (6.90 t ha^{-1}). The significant yield differences among the varieties, despite the fact that comparable top dry matter yields were produced by all varieties, may be explained by the fact that the variety with highest yield (Mareko Fana) partitioned more of its assimilates (55%) to fruits, while the variety with lowest yield (Malaga) accumulated only 37% of its assimilates in fruit on average. Average dry fruit mass and succulence were significantly affected by cultivar differences, but not by irrigation regime. Fruit number per plant was significantly affected by irrigation regime and cultivar differences. Jalapeno, a cultivar that matured early and with high harvest index, gave higher water-use efficiency in terms of fresh- (40.4 kg ha^{-1} mm^{-1}) and dry- (4.9 kg ha^{-1} mm^{-1}) fruit yield. Specific leaf area (SLA), leaf area index (LAI) and fractional interception (FI) were significantly affected by the effect of the variety. Irrigation regime significantly affected FI, but did not affect SLA and LAI.

It was concluded that irrigating between 25D and 55D is necessary for optimum yields. Furthermore, the absence of interactions between irrigation regime and cultivars for most parameters suggests that the optimum irrigation regime for best hot pepper productivity could be applied across all varieties.

Key words: Hot pepper, irrigation regime, soil water depletion, water-use efficiency

3. 1 INTRODUCTION

Hot pepper (*Capsicum annuum* L.) is a high value cash crop, of which cultivation is confined to warm and semi-arid regions of the world, where water is often a limiting factor for crop production (Kramer & Boyer, 1995). A shallow root system (Dimitrov & Ovtcharrova, 1995), high stomatal density, a large transpiring leaf surface and elevated stomata openings, make hot pepper plants susceptible to water stress (Wein, 1998; Delfine *et al*., 2000). The conventional solution to water shortages has been irrigation. However, due to competing demands for water from other sectors and increasing investment cost for irrigation, the rate of irrigation expansion is constantly decreasing (Hillel & Vlek, 2005). Therefore, adoption of land, crop and water management practices that enhance water-use efficiency of a crop are indispensable (Howell, 2001; Passioura, 2006).

Currently, irrigation techniques like water-saving irrigation and deficit irrigation are being used to increase the efficiency of irrigation (Wang et al., 2002; Deng *et al*., 2006; Fereres & Soriano, 2007). The application of drip irrigation has enhanced the water-use efficiency (WUE) of crops as compared to the more traditional irrigation methods (Xie *et al*., 1999; Antony & Singandhupe, 2004). Furthermore, other cultural practices such as cultivar selection (Ismail & Davies, 1997; Steyn, 1997; Jaimez *et al*., 1999; Collino *et al*., 2000), plant population density (Tan *et al*., 1983; Taylor *et al*., 1982), and fertilization (Ogola *et al*., 2002; Rockström, 2003) are reported to influence plant responses to irrigation water application. For instance, treatments like N fertilization (Ogola *et al*., 2002), high planting density (Ogola *et al*., 2005), and cultivars with a rapid early growth habit (Lewis & Thurling, 1994) were reported to contribute to increased WUE of plants by reducing water loss through evaporation, while increasing the water loss through transpiration. Species or cultivar differences in physiological adaptation to water shortages can also be exploited to make informed decisions on what to plant, where to plant, when to plant and what irrigation and other cultural management to use. Generally, studies demonstrated that growth and production were positively correlated with water-use due to its effects on leaf area, harvest index, mean fruit size and fruit number per plant (Chartzoulakis & Drosos, 1997; Sezen *et al*., 2006).

Hot pepper cultivars show considerable biodiversity. Cultivars differ vastly in attributes such as growth habit, length of the growing season, cultural requirements, fruit size, pigmentation and pungency (Bosland, 1992). Most experiments on C*apsicum* species have been conducted in controlled glasshouse conditions (Chartzoulakis & Drosos, 1997; Kang *et al*., 2001; Costa & Gianquinto, 2002; Dorji *et al*., 2005). Field studies on the effects of water deficit on growth, yield and water-use of hot peppers are few and inconclusive with regard to the optimum irrigation amount, due to variation in cultivars and growing conditions (Ismail & Davies, 1997; Jaimez *et al*., 1999; Delfine *et al*., 2000). Furthermore, literature on the water requirements of different hot pepper cultivars under local conditions is lacking. It is also important to understand the response of hot pepper to different levels of water deficit in order to determine the extent to which hot peppers can withstand water deficits, while maintaining acceptable yield. The objective of this study was, therefore, to establish whether hot pepper response to irrigation regime is influenced by cultivar differences. The effect of different irrigation regimes on growth, yield and water-use efficiency was evaluated in the field, with the aim of selecting the cultivars that are more efficient in water utilization.

3.2 MATERIALS AND METHODS

3.2.1 Experimental site and treatments

A field experiment was conducted on the Hatfield Experimental Farm, Pretoria, South Africa (latitude $25^0$45' S, longitude $28^0$16' E, and an altitude of 1327 m.a.s.l.) during the 2004/05 growing season. The area has an average annual rainfall of 670 mm, mainly from October to March (Annandale *et al*., 1999). The average annual maximum air temperature for the area is 25 °C and the average annual minimum air temperature is 12 °C. The hottest month of the year is January, with an average maximum air temperature of 29 °C, while the coldest months are June and July, with an average minimum air temperature of 5 °C. The soil characteristics to 30 cm soil depth are predominately sandy clay loam with permanent wilting point of 128 mm m^{-1}, field capacity of 240 mm m^{-1} and pH (H_2O) of 6.5. The soil contained 572 mg kg^{-1} Ca, 79 mg kg^{-1} K, 188 mg kg^{-1} Mg and 60.5 mg kg^{-1} Na.

Treatments were arranged in a randomized complete block strip plot design, with irrigation regime assigned to main plots and cultivars to sub-plots. The three cultivars were Mareko Fana, Jalapeno and Malaga. The three irrigation regimes were: high irrigation regime (25D, maximum of 20-25 % depletion of plant available water, DPAW), a medium irrigation regime (55D, maximum of 50-55 % DPAW) and a low irrigation regime (75D, maximum of 70-75 % DPAW). The plant available water was determined to 0.6 m soil depth. The profile was refilled to field capacity each time the predetermined soil water deficit per treatment was reached for all treatments. Subplots were 5 rows wide and 2.4 m long, with inter-row spacing of 0.7 m and intra-row spacing of 0.4 m.

3.2.2 Crop management

Six-week-old hot pepper seedlings of the respective cultivars were transplanted on November 11, 2004. Plants were irrigated using drip irrigation for 1 hour (12.5-15.5 mm) every other day for the first three weeks until plants were well established. Thereafter, plants were irrigated to field capacity, every time the predetermined soil water deficit per treatment was reached. Based on soil analysis and target yeild, 150 kg ha^{-1} N, 75 kg ha^{-1}

P and 50 kg ha^{-1} K were applied to all plots. The N application was split, with 50 kg ha^{-1} at planting, followed by a 100 kg ha^{-1} top dressing eight weeks after transplanting. Weeds were controlled manually. Preventive sprays of Benomyl® (1H – benzimidazole) and Bravo® (chlorothalonil) were applied to control fungal diseases, while red spider mites were controlled with Metasystox® (oxydemeton–methyl) applied at the recommended doses.

3.2.3 Measurements

Soil water deficit measurements were made using a model 503DR CPN Hydro probe neutron water meter (Campbell Pacific Nuclear, California, USA), which was calibrated for the site. Readings were taken twice a week, at 0.2 m increments to a depth of 1.0 m, from access tubes installed in the middle of each plot (one access tube per plot) and positioned between rows.

Data on plant growth were collected at 15 to 25 day intervals. The fractional canopy interception (FI) of photosynthetically active radiation (PAR) was measured using a sunfleck ceptometer (Decagon Devices, Pullman, Washington, USA) a day before harvest. The PAR measurement for a plot consisted of three series of measurements in rapid succession. A series of measurements consisted of one reference reading above the canopy and ten readings below the canopy. The difference between the above canopy and below canopy PAR measurements was used to calculate the fractional interception (FI) of PAR using the following equation (Jovanovic & Annandale, 1999):

$$FI_{PAR} = 1 - \left(\frac{PAR\ below\ canopy}{PAR\ above\ canopy} \right) \qquad (3.1)$$

Eight plants from the central two rows were reserved for yield measurement. Fruits were harvested three times in a season. On the final day of harvest, the whole aboveground part of plants was removed and separated into fruits, stems and leaves. Samples were then oven dried at 75 °C for 72 hours to constant mass and the dry mass determined. Leaf area was measured with an LI 3100 belt driven leaf area meter (Li-Cor, Lincoln, Nebraska, USA) and leaf area index was calculated from the leaf area and ground area from which the samples were taken. Specific leaf area was calculated as the ratio of leaf area to leaf dry mass.

Total crop evapotranspiration (ETc) was estimated using the soil water balance equation,

$$ETc = I + RF + \Delta S - D - R \quad (3.2)$$

where I is irrigation, RF is precipitation, ΔS is the change in soil water storage, D is drainage and R is runoff. Drainage was estimated using SWB model, runoff was assumed negligible as the experiment setting doses not allow free runoff.

Water-use efficiency was calculated for top dry matter, fresh fruit mass and fruit dry mass from the ratio of the respective parameter mass to calculated total evapotranspiration using eq. (3.2). Succulence, a quality measure for fresh market peppers, was calculated as the ratio of fresh fruit mass to the dry fruit mass.

3.2.4 Data analysis

Data were analyzed by using the Mixed Procedure of SAS software Version 9.1 (SAS, 2003). Treatment means were separated by the least significance difference (LSD) test at $P \leq 0.05$.

3.3 RESULTS AND DISCUSSION

3.3.1 Specific leaf area, leaf area index and canopy development

Table 3.1 presents the effect of cultivar and irrigation regime on fractional interception of photosynthetically active radiation ($FI_{(PAR)}$), leaf area index (LAI) and specific leaf area (SLA) at harvest. SLA, LAI and $FI_{(PAR)}$ were significantly affected by cultivar. Malaga gave the highest average SLA (21.14 m^2 kg^{-1}), followed by Mareko Fana (17.17 m^2 kg^{-1}) and Jalapeno (16.05 m^2 kg^{-1}). Malaga produced the highest average LAI (2.31m^2 m^{-2}) and $FI_{(PAR)}$ (0.80), while Mareko Fana produced LAI of 1.67m^2 m^{-2} and $FI_{(PAR)}$ of 0.68. The lowest average LAI (1.56 m^2 m^{-2}) and $FI_{(PAR)}$ (0.60) were recorded for Jalapeno. This shows that Malaga used less assimilate per unit leaf area as it produced more leaf area per unit of leaf dry mass as compared to the other two cultivars.

Irrigation regime affected $FI_{(PAR)}$, but did not affect SLA and LAI. $FI_{(PAR)}$ was improved by 16 % by irrigating at 25D as compared to irrigating at 75D. The irrigation regime effect between 25D and 55D, and between 55D and 75D were not significant for FI. Tesfaye *et al.* (2006) working on chickpea, cowpea and common bean observed a reduction in both $FI_{(PAR)}$ and LAI due to water stress. Joel *et al.* (1997) indicated that $FI_{(PAR)}$ could be reduced as much as 70 % due to water stress in sunflower. They attributed the reduction in $FI_{(PAR)}$ to the corresponding reduction in LAI caused by water stress. LAI decline caused by water stress was also reported for potato (Kashyap & Panda, 2003). Absence of significant effects of irrigation regime on LAI in the present study may be explained by the fact that late leaf data collection (data was collected on final harvest date) and rainfall interference during the growing season may have confounded the effect of irrigation treatment on LAI.

The SLA remained unaffected by irrigation treatment but significant cultivar differences occurred. The robustness of SLA across different irrigation treatments for the same cultivar highlights the scientific merit of using this crop-specific parameter in modelling of hot pepper under varied growing conditions (Annandale *et al*., 1999).

Table 3.1 Specific leaf area (SLA), leaf area index (LAI) and fractional interception of photosynthetically active radiation ($FI_{(PAR)}$) as affected by different irrigation regimes and hot pepper cultivars

Irrigation	Cultivar	SLA ($m^2\ kg^{-1}$)	LAI ($m^2\ m^{-2}$)	$FI_{(PAR)}$
25D	Mareko Fana	17.16	1.81	0.77
	Jalapeno	16.02	1.70	0.63
	Malaga	21.25	2.42	0.84
55D	Mareko Fana	17.20	1.79	0.66
	Jalapeno	16.07	1.50	0.60
	Malaga	21.28	2.71	0.82
75D	Mareko Fana	17.15	1.41	0.60
	Jalapeno	16.05	1.46	0.57
	Malaga	21.17	1.77	0.76
LSD	Irrigation	NS	NS	0.09*
	Cultivar	0.10**	0.51*	0.13*
	Irrigation x Cultivar	NS	NS	NS

Notes: 25D, 55D, & 75D: Irrigation at 20-25, 50-55, and 70-75 % depletion of plant available water, respectively; LSD: least significant difference ($P \leq 0.05$); NS: not significant ($P>0.05$); *: significant at $P \leq 0.05$; **: significant at $P \leq 0.01$.

3.3.2 Dry matter production and distribution

Irrigation regime significantly affected top dry matter but not leaf and stem dry matter (Figure 3.1). There were significant differences among the cultivars in stem dry matter, but not in top and leaf dry matter. Interactions between cultivars and irrigation treatments for top and leaf dry matters were not significant, but the interaction was significant for stem dry matter. Irrigating at 25D increased top dry matter by 46 % as compared to irrigating at 75D. The irrigation regime effects between 25D and 55D, and between 55D and 75D were not significant. Higher stem dry matter was produced by Malaga (2.99 t ha^{-1}) by irrigation treatment of 25D, and the lowest stem dry matter was produced by Jalapeno (1.11 t ha^{-1}) by irrigation regime of 75D. The absence of a significant effect due to irrigation regime and cultivars on leaf dry mass may be explained by the fact that leaves were harvested late into the season, after a significant proportion of the leaves had already been shed. High rainfall in the growing season may also have interfered with the irrigation regime and confounded the effects of irrigation regime on leaf dry mass.

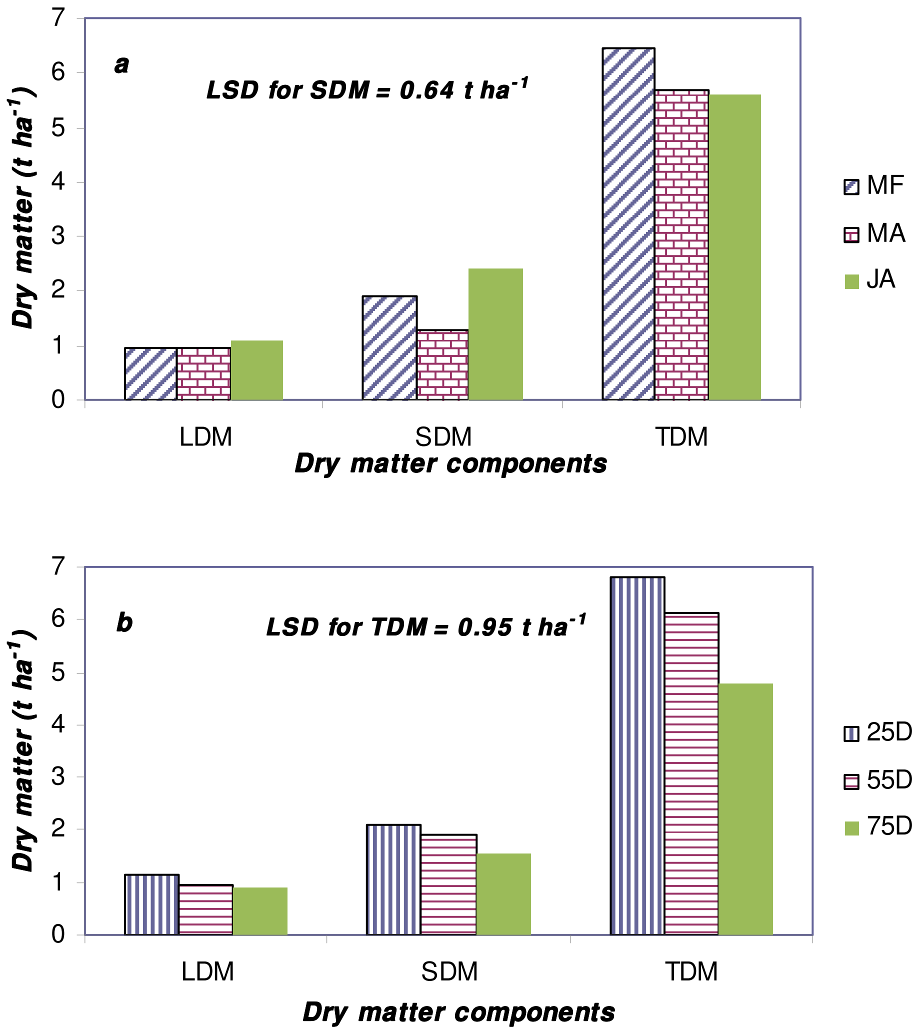

Figure 3.1 Top (TDM), leaf (LDM) and stem (SDM) dry matter as affected by cultivar (a) and irrigation regime (b). MF: Mareko Fana, MA: Malaga, JA: Jalapeno. 25D, 55D, & 75D: irrigation at 20-25, 50-55, and 70-75 % depletion of plant available water, respectively. LSD: least significant difference ($P \leq 0.05$).

Data on dry matter partitioning to fruits, leaves and stems are presented in Table 3.2. Assimilate partitioned to fruits and stems were significantly increased due to irrigating at a low soil water depletion level. Dorji *et al*. (2005), however, reported no significant differences in dry mass distribution among plant organs due to irrigation treatments. Marked differences in assimilate partitioning to fruits, leaves and stems were observed due to cultivar differences. Cultivar and irrigation regime interactions for assimilate partitioning to fruits were significant, but it was not significant for stems and leaves.

Table 3.2 Dry matters partitioning to fruits, leaves and stems as affected by different irrigation regimes and cultivars

Cultivar	Irrigation	Harvest Index	Leaf Fraction	Stem Fraction
Mareko Fana	25D	0.59 bA	0.14	0.27
	55D	0.58 aA	0.12	0.30
	75D	0.49 bB	0.19	0.32
Jalapeno	25D	0.63 aA	0.16	0.21
	55D	0.61 aA	0.16	0.23
	75D	0.58 aA	0.19	0.23
Malaga	25D	0.41 cA	0.18	0.41
	55D	0.35 bB	0.20	0.45
	75D	0.35 cB	0.21	0.44
LSD	Irrigation	0.05*	NS	0.02**
	Cultivar	0.04**	0.04*	0.03**
	Irrigation x Cultivar	0.14*	NS	NS

Notes: 25D, 55D, & 75D: irrigation at 20-25, 50-55, and 70-75 % depletion of plant available water, respectively; LSD: least significant difference ($P \leq 0.05$); NS: not significant ($P>0.05$); *: significant at $P \leq 0.05$; **: significant at $P \leq 0.01$. Column means within the same irrigation regime followed by the same lower case letter or column means within the same cultivar followed by the same upper case letter are not significantly different ($P>0.05$).

Harvest index was significantly affected by interactions between irrigation regime and cultivars. Irrigating at lower depletion level of plant available water in Mareko Fana and Malaga resulted in a significant improvement in harvest index, while in Jalapeno the effect was not significant. The highest harvest index (0.63) was observed for Jalapeno under the 25D treatment, while the lowest harvest index was observed for Malaga (55D and 75D).

Sixty percent of assimilate was portioned to fruits in Jalapeno, while it was 55 % in Mareko Fana and 37 % by Malaga. Assimilate partitioned to leaves and stems were, respectively, 17% and 22 % for Jalapeno, 15 % and 30% for Mareko Fana, and 20 % and 43 % for Malaga. Overall, fruits remained the major sink; accounting for more than 51 % of the top plant dry matter mass, followed by stems (32 %) and then leaves (17%). This result further indicated that the harvest index was significantly affected by irrigation regime, but the effect of irrigation regime is modified by cultivar differences. The harvest index reported here is higher than that of the 39% reported from split-root experiments with pot grown pepper (Cantore *et al*., 2000), whereas it closely approaches that of the 56 % reported from a deficit irrigation and partial root drying experiment on pepper (Dorji *et al*., 2005).

The significant fruit dry yield differences among the cultivars (Table 3.3), despite the fact that comparable top dry matters were produced by all cultivars, may be explained by the fact that the variety with highest yields (Mareko Fana) partitioned more of its assimilates (55%) to fruits, while the variety with lowest yield (Malaga) partitioned only 37% of its assimilates to fruits. Moreover, the cultivar with lowest yield accumulated more than 40 % of its assimilate in stems, whose contribution to photosynthesis or fruit yield is insignificant.

3.3.3 Yield, yield components and selected quality measures

Table 3.3 shows yield, yield components and selected quality traits as a function of cultivar and irrigation regime. Fresh and dry fruit yields were significantly affected by cultivar differences, and also high irrigation regime (25D) significantly increased both fresh and dry fruit yields (Table 3.3). Cultivar and irrigation regime interactions were not significant for both fresh and dry fruit yields, indicating that these parameters responded to soil water level, independent of cultivar differences When dry fruit yield of the respective cultivars are averaged over-irrigation regimes, cultivar Mareko Fana (3.60 t ha^{-1}) out-yielded Jalapeno (3.44 t ha^{-1}) and Malaga (2.11 t ha^{-1}) by 5 and 71 %, respectively. When fresh fruit yield of the respective cultivars are averaged over-irrigation regimes, higher fresh fruit yield was recorded for Jalapeno (29.28 t ha^{-1}), followed by Mareko Fana (21.49 t ha^{-1}) and Malaga (6.90 t ha^{-1}). When fresh and dry fruit yields are averaged over the cultivars, a 77 and 64 % improvement in fresh and dry yields, respectively, were observed by irrigating at 25D as compared to irrigating at 75D.

Table 3.3 Fruit yield, yield components and selected quality measures as affected by different irrigation regimes and cultivars

Irrigation	Cultivar	Fresh fruit yield (t ha^{-1})	Dry fruit yield (t ha^{-1})	Fruit (number $plant^{-1}$)	Mean fruit mass (g)	Succulence[a]
25D	Mareko Fana	28.02	4.37	67 bA	1.82	6.01 bA
	Jalapeno	38.22	4.03	46 bA	2.45	9.44 a A
	Malaga	9.71	2.96	377 aA	0.23	3.27 cA
55D	Mareko Fana	21.65	3.76	57 bA	1.87	5.91 bA
	Jalapeno	28.66	3.55	40 bA	2.46	8.01 a B
	Malaga	6.39	1.95	252 aB	0.22	3.25 cA
75D	Mareko Fana	16.36	2.76	45 bA	1.71	5.77 bA
	Jalapeno	20.97	2.75	35 bA	2.19	7.61 a B
	Malaga	4.61	1.42	183 aC	0.22	3.25 cA
LSD	Irrigation	6.526*	0.704*	41.494*	NS	NS
	Cultivar	6.430*	0.720*	37.479**	0.122**	0.416**
	Irrigation x Cultivar	NS	NS	141.250**	NS	1.637**

Notes: a: ratio of total fresh fruit mass to top dry fruit mass; 25D, 55D, & 75D: 20-25, 50-55, and 70-75 % depletion of plant available water, respectively; LSD: least significant difference ($P \leq 0.05$); NS: not significant ($P > 0.05$); *: significant at $P \leq 0.05$; **: significant at $P \leq 0.01$. Column means within the same irrigation regime followed by the same lower case letter or column means within the same cultivar followed by the same upper case letter are not significantly different ($P > 0.05$).

There were no significant differences in fresh and dry fruit yields between 25D and 55D suggesting the possibility of employing water-saving tactics. Similarly, results elsewhere reported the applicability of deficit irrigation in hot pepper production without compromising yields (Kang *et al*., 2001; Dorji *et al*., 2005). However, others confirmed the sensitivity of pepper to water stress and the beneficial effects of abundant irrigation. Costa & Gianquinto (2002) and Beese *et al*. (1982) observed significant yield increases with water rates above 100 % evapotranspiration, indicating that yield increases with more water than the well-water control. The inconsistency of the results reported may be attributed to differences in the cultivars (Ismail & Davies, 1997; Jaimez *et al*., 1999) and in the growing conditions (Pellitero *et al*., 1993).

Average dry fruit mass and succulence were significantly affected by cultivar differences, but not by irrigation regime. Cultivar and irrigation regime interactions were significant for succulence, but not for average dry fruit mass. Fruit number per plant was significantly affected by irrigation regime, cultivar differences and their interaction effect. When mean dry fruit mass was averaged across irrigation regimes, Jalapeno (2.27 g) gave higher mean dry fruit mass, followed by Mareko Fana (1.80 g) and Malaga (0.22 g). However, the number of fruits produced by respective cultivars followed the reverse order as that of mean dry fruit mass, where Malaga produced 271 fruits per plant on average, while Mareko Fana and Jalapeno produced 56 and 41 fruits per plant, respectively.

Although plants were irrigated at less frequent intervals under 55D and 75D than 25D, the mean fruit mass was not affected by irrigation regime. This may be attributed to low crop load due to high degree of flower abortion in 55D and 75D plants, compared to those plants receiving the 25D irrigation treatment (Dorji *et al*., 2005). Reduction in fruit number due to low level of soil water in 55D and 75D may have enhanced accumulation of available assimilates in the remaining fewer fruits, maintaining the final fruit mass comparable to 25D. Pepper plants are most sensitive to water stress during flowering and fruit development (Katerji *et al*., 1993). Furthermore, the existence of a consistent inverse relationship between mean dry fruit mass and fruit number per plant among the cultivars confirms the difficulty of achieving improvement in these two parameters simultaneously.

Jalapeno (8.4) was on average more succulent at harvest than Mareko Fana (5.9) and Malaga (3.3). Irrigation at a low level of soil water depletion (25D) resulted in greater succulence than when irrigating at a medium (55D) or high (75D) level of soil water depletion. Thus Jalapeno fruits harvested from plants irrigated at 25D are recommended for the fresh market, as these fruit exhibit highest succulence, which directly relates to hot pepper fruit quality.

3.3.4 Soil water content, water-use and water-use efficiency

Soil water content to 0.6 m soil depth during the growing season is shown in Figure 3.2. Soil water content within the 0.60 m soil profile decreased gradually towards the end of the season in plots irrigated at 55D and 75D. However, soil water remained higher in the plots irrigated at 25D. From the commencement of stress imposition (December 13) the soil water deficit level reached below 55D on only four occasions, whereas it never dropped below D75 due to high rainfall in the growing season. The depletion level for the 75D was higher than for 55D, and that of 55D was higher than 25D throughout the growing season, indicating that water availability was higher for 25D than 55D, followed by 75D.

Table 3.4 presents the components of soil water balance. The irrigation and rain in the different irrigation treatments, i.e., 25D, 55D and 75D was 830 mm, 731 mm and 673 mm for Mareko Fana, 740 mm, 655 mm and 616 mm for Jalapeno, and 902 mm, 792 mm and 710 mm for Malaga. The water consumption (evapotranspiration) ranged from 430 mm to 675 mm, and the observed differences in evapotranspiration among the cultivars were as a result of the differences in the length of the growing season. The water saved by irrigating at 75D as compared to 25D was 23 % for Mareko Fana, 20 % for Jalapeno, and 27 % for Malaga. Similarly, by irrigating at 55D as opposed to irrigating at 25D, on average across the cultivars, 14% of water was saved. The total irrigation events corresponding to the different irrigation treatments, i.e., 25D, 55D and 75D were 20, 11 and 9 days in Jalapeno and 26, 13 and 9 days in Malaga and Mareko Fana.

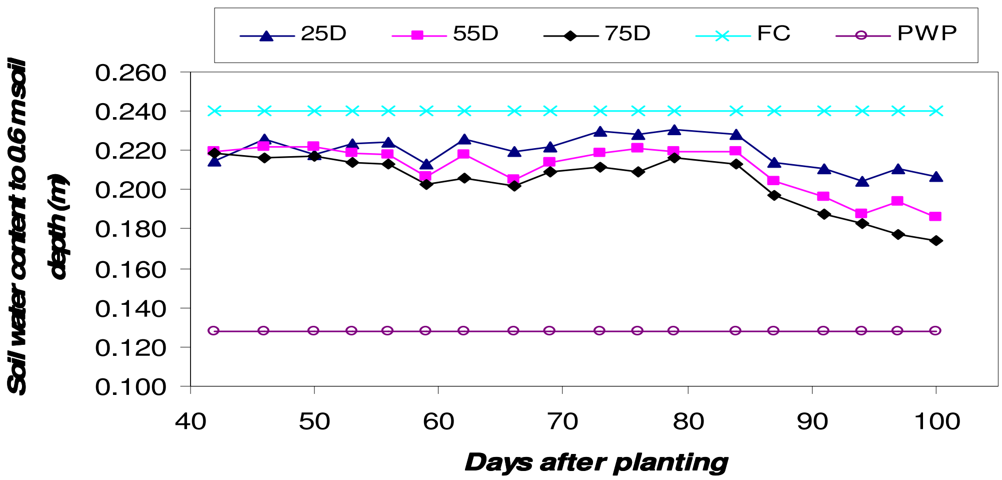

Figure 3.2 Soil water content to 0.6 m soil depth during growing season as influenced by irrigation regime. 25D, 55D, & 75D: 20-25, 50-55, and 70-75 % depletion of plant available water, respectively. FC: Field capacity, PWP: Permanent wilting point.

Table 3.4 Components of soil water balance as affected by different cultivars and irrigation regimes

Irrigation	Mm					
	Cultivar	Rainfall	Irrigation	Drainage	ΔS	ETc
25D	Mareko F.	520	310	247	3	586
	Jalapeno	463	277	236	12	516
	Malaga	557	355	243	6	675
55D	Mareko F.	520	211	220	2	513
	Jalapeno	463	192	211	11	455
	Malaga	557	235	215	4	581
75D	Mareko F.	520	153	176	-3	494
	Jalapeno	463	153	191	5	430
	Malaga	557	153	181	3	532

ΔS: change in soil water content, ETc: crop evapotranspiration.

Table 3.5 summarizes the water-use efficiency (WUE) in terms of fresh and dry fruit yields and top dry matter yields for all the treatments. The WUE in terms of fresh and dry fruit yields were significantly influenced by cultivars, but WUE for top dry matter was not affected by cultivar (Table 3.5). Irrigation regime did not affect any of the WUE considered. The cultivar and irrigation regime interaction effects for the three WUE considered were also not significant. Similarly, Katerji *et al*. (1993) using trickle irrigation, observed no significant differences in WUE between stressed and well-irrigated treatments. However, Kang *et al*. (2001) and Dorji *et al*. (2005) reported significant improvement in WUE due to water stress applied. In the present study, reduction in water application did not contribute to improvement in WUE. This is because yield and biomass were significantly reduced due to the reduction in irrigation. On average, the cultivar Jalapeno exhibited higher WUE in terms of fresh and dry fruit yields, followed by Mareko Fana and Malaga. The cultivars Jalapeno and Mareko Fana had comparable WUE in terms of top dry matter yield. The difference in WUE among the cultivars can be explained by the fact that cultivars with high WUE reached maturity earlier, with relatively high fresh as well as dry fruit yield. The absence of significant differences in WUE for top dry matter production is because all three cultivars produced comparable top dry matter yields.

Table 3.5 Water-use efficiency (WUE) as affected by different cultivars and irrigation regimes

Irrigation	Cultivar	WUE fresh fruit (kg ha^{-1} mm^{-1})	WUE dry Fruit (kg ha^{-1} mm^{-1})	WUE top dry matter (kg ha^{-1} mm^{-1})
25D	Mareko Fana	45.2	5.3	13.2
	Jalapeno	74.1	5.4	12.5
	Malaga	14.4	3.3	10.7
55D	Mareko Fana	42.2	5.2	12.7
	Jalapeno	63.0	5.4	12.7
	Malaga	11.0	2.5	9.7
75D	Mareko Fana	33.1	4.1	11.3
	Jalapeno	48.8	4.5	11.1
	Malaga	8.7	2.0	7.6
LSD	Irrigation	NS	NS	NS
	Cultivar	12.57**	1.50**	NS
	Irrigation X Cultivar	NS	NS	NS

Notes: 25D, 55D, & 75D: irrigation at 20-25, 50-55, and 70-75 % depletion of plant available water, respectively; LSD: least significant difference ($P \leq 0.05$); NS: not significant ($P>0.05$); *: significant at $P \leq 0.05$; **: significant at $P \leq 0.01$.

3.4 CONCLUSIONS

This study demonstrated that highest yield under rainfed conditions with supplemental irrigation in Pretoria would be obtained by maintaining the depletion of soil water level between 20 and 55%. The absence of significant differences in fresh and dry fruit yields between 25D and 55D, suggests the potential of practicing deficit irrigation.

Despite comparable top dry biomass yields, the cultivars produced significantly different dry and fresh fruit yields. This is due to the fact that the dry yield differences among the cultivars were more attributed to differences in harvest index and average fruit mass, than leaf area, top biomass or fruit number differences. The WUE did not improve by irrigating at higher level of plant water depletion, as the corresponding yield reduction per unit water saved outweighed the yield gain per unit water applied. Significant differences in WUE for fresh and dry fruit yields were observed among the cultivars. This is attributed to early maturity, high harvest index and high succulence by those cultivars with high WUE for fresh and dry fruit yields. There were no significant interaction effects observed for most parameters which revealed that hot pepper response to irrigation regime was the same for all cultivars. It appears that an appropriate irrigation regime that maximizes production of hot pepper can be devised across cultivars.

Finally, where the cost of fresh water is high, further research is recommended to establish an irrigation regime involving deficit irrigation by quantifying the trade-off between the yield loss that would be incurred because of irrigation at levels that are below the optimum and the economical and ecological advantage that would be achieved by practicing deficit irrigation.

CHAPTER 4

RESPONSE OF HOT PEPPER (*Capsicum annuum* L.) CULTIVARS TO DIFFERENT ROW SPACINGS

Abstract

A field trial was conducted in the 2004/2005 growing season at the Hatfield Experimental Farm, University of Pretoria, to investigate the effect of different row spacings and cultivars on growth, yield and water-use efficiency with the aim of selecting the cultivars that are more efficient in resource utilization. Treatments were arranged in a randomized complete block strip plot design, where the row spacings and cultivars were assigned to main plots and sub plots, respectively. The three cultivars were Jalapeno, Malaga and Serrano, and the two row spacings 0.45 m and 0.70 m. Treatments were replicated three times and drip irrigation was utilized. Growth analysis, soil water content and yield measurements were performed.

Cultivar Jalapeno (4.24 t ha^{-1}) out-yielded Serrano (2.67 t ha^{-1}) and Malaga (2.50 t ha^{-1}) in dry fruit yield. Higher fresh yield was also recorded for Jalapeno (38.61 t ha^{-1}), followed by Serrano (15.62 t ha^{-1}) and Malaga (8.05 t ha^{-1}). A 25% and 22% improvement in fresh fruit and dry fruit yields, respectively, was observed by planting at a row spacing of 0.45 m, as compared to planting at a row spacing of 0.70 m. Fruit number per plant increased from 112 to 127 as row spacing increased from 0.45 m to 0.70 m, indicating a compensatory growth response by individual plants to offset yield reduction due to wide row spacing. The high fruit dry mass recorded in Jalapeno (4.24 t ha^{-1}), in spite of low fruit number per plant, is attributed to its high harvest index (0.64) and high average fruit dry mass (2.44 g). Malaga produced the highest fruit number per plant (245), but yielded the lowest dry and fresh fruit yield due to its relatively low harvest index (0.40) and low average fruit dry mass (0.23 g). The existence of a consistent inverse relationship between average dry fruit mass and fruit number per plant among the cultivars confirms the difficulty of achieving improvement in those two parameters concomitantly.

No significant interaction effect was observed for most parameters studied; revealing that hot pepper response to row spacing did not depend on cultivar differences. Thus, it appears that appropriate row spacing that maximizes production of hot pepper can be devised across cultivars having similar growth habit to ones studied here.

Key words: Hot pepper, plant density, row spacing, water-use efficiency

4.1 INTRODUCTION

Hot pepper cultivars show considerable biodiversity: cultivars differ vastly in attributes such as growth habit, length of growing season, cultural requirements, fruit size, pigmentation and pungency (Bosland, 1992). Production and harvesting costs are high in hot pepper, as the crop is capital- (irrigation & other inputs) and labour-intensive. Managing production inputs and minimizing production costs are increasingly important for profitable hot pepper production. Row spacing is one of the cultural practices that influence productivity of a crop (Kelley & Boyhan, 2006).

Optimum plant population or in-row plant spacing studies have been conducted on bell (Russo, 1991; Locascio & Stall, 1994), cayenne (Decoteau & Graham, 1994), pepperoncini (Motsenbocker, 1996), paprika (Kahn *et al*., 1997; Cavero *et al*., 2001), and pimiento peppers (Ortega *et al*., 2004). However, recommendations suggested by each investigator vary widely. For instance, Decoteau & Graham (1994) reported 44 400 plants ha^{-1} for optimum cayenne pepper production, while Ortega *et al*. (2004) recommended plant densities in the range of 100 000 to 120 000 plants ha^{-1} for pimiento pepper. This is because optimum plant population density for a given species varies depending on cultivar, input level, harvesting techniques and other cultural practices.

Generally, high density planting is associated with high yields. High density planting also aids mechanical harvesting, as more fruits set on higher plant canopy (Decoteau & Graham, 1994). However, disease incidence due to reduced ventilation (Karlen *et al*., 1987; Stofella & Bryan, 1988) and poor colour development of fruits due to reduced light exposure (Stofella & Bryan, 1988; Cavero *et al*., 2001) are some of the limitations of high density planting. Thus, it appears that a compromise is made between yield, quality and ease of performing cultural practices when the producer has to decide the best planting density.

Literature reviewed so far indicated that most researchers considered only one or two cultivars in their studies, and little information is available on how the different growth components of pepper are affected by row spacing to ultimately determine the performance of hot pepper cultivars. Information on how row spacing affects yield and growth of different hot pepper cultivars has not been well elucidated under field conditions in the Pretoria area. Furthermore, literature on the impact of varying the plant population of hot pepper on canopy growth is inadequate. Cognizant of the diversity of hot peppers and the sparse information available on plant population effects on performance of hot pepper, a field experiment was conducted with the objective to investigate effects of different row spacings on yield, quality and growth of hot pepper cultivars.

4.2 MATERIALS AND METHODS

4.2.1 Experimental site and treatments

A field experiment was conducted at the Hatfield Experimental Farm, Pretoria, South Africa (latitude $25^0 45'$ S, longitude $28^0 16'$ E, altitude 1327 m.a.s.l.). The area has an average annual rainfall of 670 mm, mainly from October to March (Annandale *et al.*, 1999). The average annual maximum air temperature for the area is 25 °C and the average annual minimum air temperature is 12 °C. The hottest month of the year is January, with an average maximum air temperature of 29 °C, while the coldest months are June and July, with an average minimum air temperature of 5 °C. The soil characteristics to 30 cm soil depth are predominately sandy clay loam with permanent wilting point of 128 mm m^{-1}, field capacity of 240 mm m^{-1} and pH of 6.5. The soil contained 572 mg Ca, 79 mg K, 188mg Mg and 60.5 mg Na per one kg of dry soil.

Treatments were arranged in randomized complete block strip plot design, where the row spacings and cultivars were assigned to main plot and sub plots, respectively. The two row spacings were 0.7 x 0.4 m and 0.45 x 0.4 m, which corresponded to 35714 and 55555 plants ha^{-1}, respectively. The three cultivars were Serrano, Jalapeno and Malaga.

4.2.2 Crop management

Six-week-old hot pepper transplants of the respective cultivars were transplanted on 11 November, 2004. Plants were irrigated using drip irrigation for 1 hour (12.5-15.5 mm) every other day for three weeks until plants were well established. Thereafter, the soil profile was refilled to field capacity, every time when the measured soil water deficit level reached 50-55% depletion of plant available water. Based on soil analysis results and target yield, 150 kg ha^{-1} N, 75 kg ha^{-1} P and 50 kg ha^{-1} K were applied to all plots. The N application was split, with 50 kg ha^{-1} at planting, followed by a 100 kg ha^{-1} top dressing eight weeks after transplanting. Weeds were controlled manually. Fungal diseases were controlled using Benomyl® (1H – benzimidazole) and Bravo® (chlorothalonil) sprays, while red spider mites were controlled with Metasystox® (oxydemeton–methyl) applied at the recommended doses.

4.2.3 Measurements

Eight plants from the central two rows of each plot were marked for yield measurement. Fruits were harvested three times during the season. On the final day of harvest, all aboveground plant parts were harvested and separated into fruits, stems and leaves and whereafter they were oven dried at 75 °C for 72 hours to constant mass, and dry mass was determined. Leaf area was measured with an LI 3100 belt driven leaf area meter (Li-Cor, Lincoln, Nebraska, USA). Leaf area index was calculated from the leaf area and ground area from which the samples were taken. Specific leaf area was calculated as the ratio of leaf area to leaf dry mass.

The fraction of photosynthetically active radiation intercepted (FI_{PAR}) by the canopy was measured using a sunfleck ceptometer (Decagon Devices, Pullman, Washington, USA) a day before harvest. The photosynthetically active radiation (PAR) measurement for a plot consisted of three series of measurements in rapid succession. A series of measurements consisted of one reference reading above the canopy and ten readings below the canopy. The difference between the above canopy and below canopy PAR measurements was used to calculate the fractional interception (FI) of PAR using the following equation (Jovanovic & Annandale, 1999).

$$FI_{PAR} = 1 - \left(\frac{PAR\, below\ canopy}{PAR\ above\ canopy} \right) \tag{4.1}$$

Total crop evapotranspiration (ETc) was estimated using the soil water balance equation,

$$ETc = I + RF + \Delta S - D - R \tag{4.2}$$

where I is irrigation, RF is precipitation, ΔS is the change in soil water storage, D is drainage and R is runoff. Drainage was estimated using SWB model, runoff was assumed negligible as the experiment setting doses not allow free runoff.

Water-use efficiency was calculated for top dry matter, fresh fruit mass and fruit dry mass from the ratio of the respective parameter mass to calculated total evapotranspiration using eq. (3.2). Succulence, a quality measure for fresh market peppers, was calculated as the ratio of fresh fruit mass to the dry fruit mass.

4.2.4 Data analysis

Data was analyzed using the Mixed Procedure of SAS software Version 9.1 (SAS, 2003). Treatment means were separated by the least significance difference (LSD) test at $P \leq 0.05$.

4.3 RESULTS AND DISCUSSION

4.3.1 Specific leaf area, leaf area index and canopy development

Table 4.1 presents the results of the effect of row spacing and cultivar differences on specific leaf area (SLA), leaf area index (LAI) and fractional interception (FI). The main effect of cultivar was highly significant (P≤0.01) for SLA, LAI and FI. Row spacing highly significantly (P≤0.01) affected LAI and FI, but not SLA. Decreasing row spacing increased FI on average from 0.66 to 0.77. The FI measured was significantly different between Serrano (0.73) and Jalapeno (0.64), and between Malaga (0.78) and Jalapeno (0.64), while FI of Serrano (0.73) and that of Malaga (0.78) did not differ significantly. A significant difference in SLA was observed among the three cultivars, with Serrano being the highest and Jalapeno the lowest.

Table 4.1 Specific leaf area (SLA), leaf area index (LAI) and fractional interception (FI) as affected by different row spacings and cultivars

Row spacing	Cultivar	SLA (m^2 kg^{-1})	LAI (m^2 m^{-2})	FI
0.45 m	Serrano	20.55	1.84 Aa	0.77
	Jalapeno	16.08	1.80 Aa	0.73
	Malaga	18.15	2.48 aB	0.83
0.70 m	Serrano	20.43	1.10 Ba	0.70
	Jalapeno	15.79	1.54 bB	0.55
	Malaga	18.09	1.78 bB	0.72
LSD	Row spacing	NS	0.141**	0.048**
	Cultivar	0.533**	0.394**	0.111**
	Row spacing x Cultivar	NS	0.401**	NS

Notes: LSD: least significant difference (P ≤ 0.05); NS: not significant (P>0.05); *: significant at P ≤ 0.05; **: significant at P ≤ 0.01. Column means within the same cultivar followed by the same lower case letter or column means within the same row spacing followed by the same upper case letter are not significantly different (P>0.05).

The cultivar and row spacing interaction effect was significant for LAI, but not for SLA and FI. Highest LAI (2.48 m^2 m^{-2}) was recorded in Malaga at a row spacing of 0.45 m, while the lowest LAI (1.10 m^2 m^{-2}) was observed in Jalapeno at a row spacing of 0.7 m.

The relationship between LAI and FI, or SLA and LAI is not usually direct. For instance, on average the relatively high LAI recorded for Jalapeno (1.67 m^2 m^{-2}) in relation to Serrano (1.47 m^2 m^{-2}) did not result in higher FI for Jalapeno (0.64) as compared to Serrano (0.73). Furthermore, the high mean SLA observed in Serrano (20.49 m^2 kg^{-1}) as compared to Jalapeno (15.94 m^2 kg^{-1}) did not result in higher LAI for Serrano (1.47 m^2 m^{-2}) as compared to Jalapeno (1.67 m^2 m^{-2}). This is because FI is affected not only by the size of the canopy but also by the way in which the leaves are configured in a canopy (Russell *et al*., 1990). Similarly, SLA reflects the dry leaves mass contained in a unit of leaf area. Thus depending on cultivars' difference, cultivars with thin leaves with similar leaf area would have a high SLA, which is an indicator of high productivity (Wilson *et al*., 1999).

The present study has shown an improved light interception as row spacing decreased from 0.70 m to 0.45 m. Lorezo & Catilla (1995) reported also higher LAI and a marked improvement in radiation interception as plant populations increased in hot pepper. Flénet *et al*. (1996), working on four different crop species (maize, sorghum, soybean and sunflower), reported an improvement in light interception ability as row spacing decreased and attributed it to the even distribution of plants and hence foliage in narrower row spacing. Taylor *et al*. (1982) observed no significant increase in LAI of soybean due to higher density planting. However, light interception was consistently greater in 0.25 m row spacing than 1.0 m row spacing, which they attributed to a more even leaf distribution in the narrow row spacing. The robustness of SLA across different row spacings highlights the reliability of using this crop-specific parameter in modelling of hot pepper under varied growing conditions (Annandale *et al*., 1999).

4.3.2 Dry matter production and partitioning

Dry matter production as affected by row spacing and cultivar is presented in Table 4.2. Top dry matter, leaf dry matter and stem dry matter were significantly improved as a result of increasing planting density. A significant difference in leaf dry matter and stem dry matter were observed among the cultivars, but the top dry matter production was not affected by cultivar. The cultivar and row spacing interaction effect was significant for leaf dry matter, but there was no interaction between top dry matter and stem dry matter.

An increase of 27.8 % in top dry matter, 33.6 % in leaf dry matter and 33.7 % in stem dry matter was observed as the row spacing decreased from 0.70 to 0.45 m. Cultivar Malaga produced the highest leaf dry matter (1.176 t ha^{-1}) and stem dry matter (2.649 t ha^{-1}), whereas the lowest leaf dry matter and stem dry matter was recorded in Serrano (0.717 t ha^{-1}) and Jalapeno (1.358 t ha^{-1}), respectively.

Table 4.2 Top dry matter (TDM), leaf dry matter (LDM) and stem dry matter (SDM) as affected by different row spacings and cultivars

Row spacing	Cultivar	TDM (t ha^{-1})	LDM (t ha^{-1})	SDM (t ha^{-1})
0.45 m	Serrano	6.476	0.896 aA	2.580
	Jalapeno	7.076	1.109 aB	1.480
	Malaga	7.313	1.358 aC	3.092
0.70 m	Serrano	4.782	0.538 bA	1.908
	Jalapeno	6.211	0.986 bB	1.236
	Malaga	5.539	0.993 aB	2.206
LSD	Row spacing	1.13**	0.07**	0.59**
	Cultivar	NS	0.23**	0.87**
	Row spacing x Cultivar	NS	0.23**	NS

Notes: LSD: least significant difference (P≤ 0.05); NS: not significant (P>0.05); *: significant at P ≤ 0.05; **: significant at P ≤ 0.01. Column means within the same cultivar followed by the same lower case letter or column means within the same row spacing followed by the same upper case letter are not significantly different (P>0.05).

Data on dry matter partitioning to fruit, leaf and stem as affected by row spacing and cultivar difference is presented in Table 4.3. Marked differences in assimilate partitioning to fruit, leaf and stem was observed due to cultivar differences. The proportion of assimilate portioned to fruit in Jalapeno was 64 %, while in Serrano it was 47 % and in Malaga it was 40 %. Assimilate partitioned to leaf and stem were, respectively, 16% and 20 % for Jalapeno, 13% and 40% for Serrano and 19% and 41% for Malaga. Overall, fruits remained the major sink, accounting for more than 50 % of the top plant dry matter mass, followed by stem (34 %) and then leaf (16%). The average harvest index reported

Table 4.3 Dry matter partitioning to fruits, leaves and stems as affected by different row spacings and cultivars

Row spacing	Cultivar	Harvest Index	Leaf Fraction	Stem Fraction
0.45 m	Serrano	0.46	0.14	0.30
	Jalapeno	0.63	0.16	0.21
	Malaga	0.39	0.19	0.42
0.70 m	Serrano	0.48	0.11	0.41
	Jalapeno	0.64	0.16	0.20
	Malaga	0.40	0.19	0.41
LSD	Row spacing	NS	NS	NS
	Cultivar	0.08**	0.03**	0.06**
	Row spacing x Cultivar	NS	NS	NS

Notes: LSD: least significant difference ($P \leq 0.05$); NS: not significant ($P > 0.05$); *: significant at $P \leq 0.05$; **: significant at $P \leq 0.01$.

for the cultivars is higher than the 39% reported for a split-root experiment on pot-grown pepper (Cantore *et al*., 2000), whereas it closely approaches that of 56 % reported from a deficit irrigation and partial root drying experiment on pepper (Dorji *et al*., 2005). In agreement with the present finding, Jolliffe & Gaye (1995) also reported no significant effect on harvest index as plant population changed from 1.4 to 11.1 plants m^{-2} in bell pepper. The result of the present study confirmed that dry matter partitioning is a cultivar trait and is hardly affected by growing conditions. Neither row spacing nor the interaction between row spacing and cultivar were significant for assimilates partitioning.

The significant fruit yield differences (Table 4.4) among the cultivars, despite the fact that comparable top dry matter yields (Table 4.2) have been produced by all cultivars, may be explained by the fact that top yielding cultivar (Jalapeno) partitioned more of its assimilates (64%) to fruit, while cultivar with lowest fruit yield (Malaga) accumulated only 40% of its assimilates in fruits (Table 4.3). Moreover, cultivar Malaga, with lowest yield, accumulated more than 41% of assimilates in stems, which contributed insignificantly to photosynthesis or fruit yield.

4.3.3 Fruit yield, yield components and selected quality measures

Table 4.4 shows yield, yield components and selected quality measures as a function of row spacing and cultivar difference. Fresh and dry fruit yields were significantly affected by cultivar differences. High planting density significantly increased both fresh and dry fruit yields (Table 4.4). Cultivar and row spacing interaction was not significant for both fresh and dry fruit yields, indicating that these parameters responded to row spacing treatment independent of cultivar differences.

Cultivar Jalapeno (4.24 t ha^{-1}) out-yielded Serrano (2.67 t ha^{-1}) and Malaga (2.50 t ha^{-1}) by 59 % and 69 %, respectively, in dry fruit yield. Higher fresh fruit yield was recorded for Jalapeno (38.61 t ha^{-1}), followed by Serrano (15.62 t ha^{-1}) and Malaga (8.05 t ha^{-1}). A 25% improvement in fresh fruit and 22% dry fruit yields were observed by planting at row a spacing of 0.45 m, as compared to row spacing of 0.70 m.

Fruit number per plant was significantly affected by row spacing and cultivar. Average dry fruit mass and succulence were significantly affected by cultivar differences, but not by row spacing. Cultivar and row spacing interaction effect was not significant for fruit number per plant, average fruit mass and succulence.

Fruit number per plant increased from 112 to 127 as row spacing increased from 0.45 m to 0.70 m, indicating a compensatory growth response by individual plants to offset the yield reduction due to wider row spacing. The higher productivity observed due to narrow row spacing as compared to wide row spacing is attributed to higher top dry mass and fruit dry mass per unit area of land. The cumulative compensatory growths effects (fruit number per plant, average fruit mass, individual plant dry matter production) observed for wide row spacing were not adequate enough to offset the yield reduction incurred as a result of the wider row spacing. Fruit number per plant and average fruit mass exhibited an inverse relationship across all three cultivars.

Table 4.4 Fruit yield, yield components and selected quality measures as affected by different row spacings and cultivars

Row spacing	Cultivar	Fresh fruit Yield (t ha^{-1})	Dry fruit yield (t ha^{-1})	Fruit number $plant^{-1}$	Average fruit mass (g)	Succulence
0.45 m	Serrano	17.83	3.00	68	0.80	5.95
	Jalapeno	41.99	4.49	33	2.45	9.10
	Malaga	9.44	2.86	235	0.22	3.31
0.70 m	Serrano	13.41	2.34	79	0.81	5.81
	Jalapeno	35.24	3.99	46	2.42	9.11
	Malaga	6.760	2.14	255	0.24	3.12
LSD	Row spacing	6.01*	0.83**	16.51*	NS	NS
	Cultivar	8.14**	1.11**	38.83**	0.19**	0.45**
	Row spacing x Cultivar	NS	NS	NS	NS	NS

Notes: LSD: least significant difference ($P \leq 0.05$); NS: not significant ($P>0.05$); *: significant at $P \leq 0.05$; **: significant at $P \leq 0.01$.

The high fruit dry mass recorded in Jalapeno (4.24 t ha^{-1}), in spite of low fruit number per plant, is attributed to its high harvest index (0.64) and high average fruit mass (2.44 g). Malaga produced the highest fruit number per plant (245), but yielded the lowest dry and fresh fruit yield due to its relatively low harvest index (0.40) and low average fruit mass (0.23 g). The existence of a consistent inverse relationship between average dry fruit mass and fruit number per plant among the cultivars confirms the difficulty of achieving improvement in those two parameters concomitantly.

Jalapeno exhibited a higher degree of succulence (9.11) at harvest than Serrano (5.89) or Malaga (3.21). The high variation in fresh fruit yield per unit of land observed among the cultivars is partly attributable to the marked difference in the degree of succulence among the cultivars (Table 4.4).

In agreement with the present findings, Lorezo & Catilla (1995) observed an increase in yield of bell pepper as planting density was increased. They attributed the effect to increased LAI, which in turn improved radiation interception. Jolliffe & Gaye (1995) reported as much as a 47% variation in total fruit dry yield of pepper that was harvested 103 days after transplanting and attributed this to population density effects. At the end of the growing season plant population density treatments accounted for 35% of the variation in the final cumulative fruit dry mass. Similarly, the increase in plant productivity was considered to result from the increase in plant population for Tabasco pepper (Sundstorm *et al*., 1984); bell pepper (Stoffella & Bryan, 1988); cayenne pepper (Decoteau & Graham, 1994) and pepperoncini (Motsenbocker, 1996) until optimum plant population is reached, beyond which yield reported to decrease due to intra-species competition.

4.3.4 Water-use and water-use efficiency

Table 4.5 presents the components of soil water balance. The water consumption (evapotranspiration) ranged from 451 mm to 552 mm, and the observed differences in evapotranspiration among the cultivars were as a result of the differences in the length of the growing season. Table 4.6 the water-use efficiency (WUE) in terms of fresh and dry fruit yields and top dry matter, as influenced by cultivar and row spacing. WUE in terms of top dry matter and fresh and dry fruit yields were significantly influenced by cultivars and row spacing (Table 4.6). The cultivar and row spacing interaction effect for the three WUE considered was not significant. In the present study, reducing the row spacing from 0.7 to 0.45 m increased the WUE. This is because yield and biomass were significantly improved due to decreasing the row spacing, but the water supply (irrigation plus rain) was the same for the two row spacings. The cultivar Jalapeno exhibited higher WUE, followed by Serrano and Malaga. The difference in WUE among the cultivars can be explained by the fact that cultivars with high WUE mature earlier, with relatively high fresh and dry fruit yield.

Table 4.5 Components of soil water balance as affected by different cultivars and row spacing

Row spacing		mm				
	Cultivar	Rainfall	Irrigation	Drainage	ΔS	ETc
0.45 m	Serrano	521	220	247	-5	521
	Jalapeno	458	190	236	6	458
	Malaga	552	233	243	4	552
0.70 m	Serrano	521	220	220	2	523
	Jalapeno	458	190	211	11	451
	Malaga	552	233	215	2	538

ΔS: change in soil water content, ETc: crop evapotranspiration.

Table 4.6 Water-use efficiency as affected by different hot pepper cultivars and row spacings

Row spacing	Cultivar	WUE fresh fruit kg ha^{-1} mm^{-1})	WUE dry fruit (kg ha^{-1} mm^{-1})	WUE top dry matter yield (kg ha^{-1} mm^{-1})
0.45 m	Serrano	34.2	5.8	12.4
	Jalapeno	91.7	9.8	15.5
	Malaga	17.1	5.2	13.2
0.70 m	Serrano	25.6	4.5	9.1
	Jalapeno	78.1	8.8	13.8
	Malaga	12.4	4.0	9.9
LSD	Row spacing	8.3*	1.0*	1.53**
	Cultivar	17.4**	1.65**	2.0**
	Row spacing x Cultivar	NS	NS	NS

Notes: LSD: least significant difference ($P \leq 0.05$); NS: not significant ($P>0.05$); *: significant at $P \leq 0.05$; **: significant at $P \leq 0.01$.

4.4. CONCLUSIONS

Results from the present study indicate that high density planting markedly increased growth and yield per unit area. Except fruit number per plant, yield components such as average fruit mass and harvest index were unaffected by row spacing. This indicates that the change in those important yield compensation processes were not adequate to offset the yield reduction due to wide row spacing planting. Thus, the yield increment recorded in the narrow row spacing is due to high biomass production per unit area, which in turn is attributable to the improved light interception in those plants planted in narrow row spacing.

Although all cultivars produced comparable top dry biomass, dry and fresh fruit yields were significantly different among the cultivars. Malaga, a cultivar with the highest leaf area, leaf mass and fruit number per plant, yielded the least. Jalapeno, a cultivar with the highest harvest index and average fruit mass, produced the highest fresh and dry fruit yields. Thus, the yield difference among the cultivars was more attributable to differences in harvest index and average fruit mass rather than leaf area, top biomass or fruit number differences. Hot pepper breeders working on yield improvement should target harvest index and average fruit mass in their effort to breed high yielding cultivars. The wide gap in fresh fruit yield per unit land among the cultivars is attributed to the marked difference among the cultivar in their succulence at harvest. High density planting by virtue of its high yield per unit area resulted in improved water-use efficiency. Cultivars with high water-use efficiency can be obtained by selecting those that mature earlier with relatively high fresh and dry fruit yield.

No significant interaction effects were observed for most parameters studied; revealing that hot pepper response to row spacing did not depend on cultivar differences. Thus, it appears that appropriate row spacing, which maximizes production of hot pepper, can be devised across cultivars having similar growth habit with the ones considered in this study.