Sabaramuwa University Journal
Volume ...., 2nd International Symposium (Proceedings) 2008, pp 137-151
ISSN 1391-3166

Effect of Water Stress Imposed at Different Growth Stages on Growth and Yield of Two Varieties of *Capsicum annum* L.

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Abstract

Water availability is an important factor in determining yield of Capsicum. The response to water stress in capsicum could vary on the growth stage. Therefore, the objective of this study was to determine the effects of water stress imposed at vegetative and reproductive stages on the growth and yield of two selected capsicum varieties (HYW and CA8). Plants were grown in pots in a rain sheltered plant house in zone $IL1_a$. Water stressed (**S**) and well watered (**W**) conditions were imposed at vegetative and reproductive stages as: **WW**-well watered in both vegetative (V) and reproductive (R) stages; **WS**-well watered in V and water stressed in R; **SW**-water stressed in V and well watered in R and **SS**-water stressed in both V and R. At 50% flowering, plant water potential, fresh and dry weights and leaf area per plant were significantly greater in WW and WS than in SW and SS. At the reproductive stage (50% flowering), water potential was significantly greater WW and SW than in WS and SS. Fresh and dry weights and leaf area per plant showed a decreasing trend for WW, WS, SW, SS respectively in both varieties. Greatest yield reductions were observed in SS, with 66% and 95% in HYW and CA-8 respectively. In both varieties, water stress at the reproductive stage caused a greater yield loss than at the vegetative stage. Therefore, pod numbers and weight per pod decreased. However, no advantage of greater rooting ability on yield under water-limited conditions.

Key words: Water stress, Vegetative stage, Reproductive stage, Capsicum, Yiel

Introduction

The Capsicum plant belongs to the family Solanaceae and genus Capsicum. Capsicum annum is the most popular and the most common variety in Sri Lanka. It is now widely cultivated in the wet and dry zones of Sri Lanka (Anonymous, 1993). There are several varieties of Capsicum annum. One of the important varieties is 'Capsicum', generally called as Malumiris, which is commonly used as vegetable. The cultivated extent of capsicum in Sri Lanka was 2,992 ha in 2005 with an average production of 4.34 mt/ha (Anonymous, 2007). More than 72% of the crop was produced in Badulla, Nuwara Eliya, Kurunegala, Matale and Monaragala districts.

CA-8 and Hangarian Yellow Wax (HYW) are the Department of Agriculture (DOA) recommended capsicum varieties. HYW is an exotic variety having shiny light yellow coloured, conical shaped pods. CA-8 has light green pods. HYW is widely cultivated as it fetches a better price in the market because of its shape and colour of pods.

Capsicum is grown successfully in both the wet and dry zones of Sri Lanka. It is cultivated as a rainfed crop in the Maha season and as an irrigated crop after Maha rains. The Yala season cultivation is mainly in the lowlands and highlands with irrigation facilities. Due to the limited rainfall during Yala, capsicum experiences frequent soil moisture deficits during different parts of the growing period. Water stress conditions prevailing during different growth stages severely affect the plant physiological activities. As a resulting capsicum showed poor growth performance and yield reduction (Wien, 1997).

Hence, identification of the degree of drought resistance in different capsicum varieties and the most drought sensitive growth stage is vital for minimizing yield reductions under water stressed conditions. Therefore, the objectives of the present study were to evaluate the two main capsicum varieties (HYW and CA-8) based on growth performances and yield responses to water stress imposed during two different growth stages (vegetative and reproductive) and to determine the physiological basis of yield reduction of capsicum under water stressed conditions.

Materials and Methods

A pot experiment was conducted during the period from December 2006 to May 2007 in a rain-sheltered planthouse at the Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, Gonawila, Sri Lanka (7^0 20'N latitude, 80^0 00'E longitude and 25 m altitude) situated in the Low Country Intermediate zone, $IL1_a$ (Punyawardena et al., 2003).

Two capsicum varieties namely Hangarian Yellow Wax (HYW) and CA-8 were evaluated for their growth performances and yield responses to water stress which imposed at two different growth stages. The treatment structure was a three-factor factorial with the two varieties, two water regimes and two stages of water stress imposition (Table 1), altogether making eight treatment combinations. Each treatment combination had thirty replicate plants which were laid out in a Randomized Complete Block Design.

Table 1: Definition of experimental treatment combinations with variety, water regime and growth

Variety	Growth Stage		Water Regime
	Vegetative	Reproductive	
HYW	W	W	WW
	W	S	WS
	S	W	SW
	S	S	SS
CA-8	W	W	WW
	W	S	WS
	S	W	SW
	S	S	SS

One month old seedlings were transplanted to pots filled with the potting mixture of sand : cow dung : compost : top soil in 1:1:1:1 ratio. A basal fertilizer mixture containing 220 kg/ha of urea, 380 kg/ha of triple supper phosphate, 125 kg/ha of muriate of potash was incorporated at the time of pot filling. A top dressing of 45 kg/ha of urea, 25 kg/ha of muriate of potash was applied 4 and 8 weeks after planting. The plants were arranged at a spacing of 15 cm × 30 cm. Except for watering, all other management practices were done similarly for all treatments, according to DOA recommendations.

Well watered (W) and water stressed (S) conditions were maintained by providing pre-tested water levels (Table 2). This watering schedule was started two weeks after transplanting, once the seedlings were well established in the pots.

Table 2: Amount of water applied at different watering regimes

Vegetative stage	Well watered(W)	150 ml / Daily watering
	Water stressed(S)	50 ml / Watering at two day intervals
Reproductive stage	Well watered(W)	250 ml / Daily watering
	Water stressed(S)	100 ml / Watering at two day intervals

Beginning of the reproductive stage was considered as 50% of flowering.

Fresh weights and dry weights of different plant parts, plant height, leaf area and plant water potential values were measured at the vegetative stage (at 35 days after transplanting before 50% flowering) and the reproductive stage (at 65 days after transplanting) of the capsicum plants. Destructive plants samples were randomly selected from each treatment combination from every block to get the above measurements. Plant fresh weight was measured just after plant removal for destructive sampling. Plant dry weights were measured after oven drying at 80 ^{0}C for 48 hours. Leaf area per plant was measured by an automatic leaf area meter (Area meter AM100, ADC Plant Science Instrumentation, UK) and the plant water potential was measured using a Scholander pressure chamber soon after the stem was cut 10 cm below the apical bud. Plant height from the soil level up to the apical bud of the main stem was taken as the plant height.

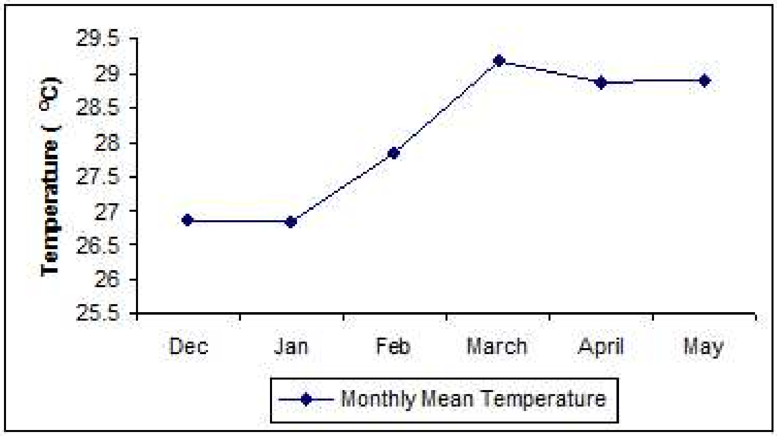
Three plants from each treatment combination from every block were tagged for continuous yield monitoring and pod yield was recorded at fortnightly intervals. In addition to pod yield, numbers of pods were also counted. Harvest index was calculated as the ratio between the fresh weights of total pod yield per plant and total fresh weight per plant at final harvest.

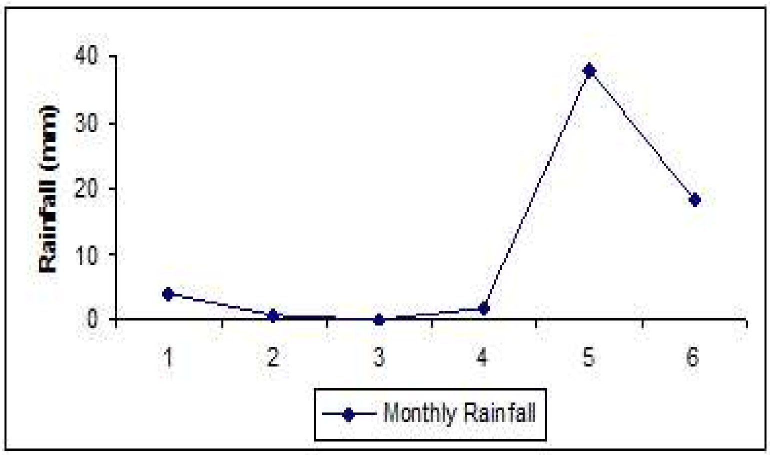
The of treatment effects were tested by analysis of variance (ANOVA) using the SAS statistical package. Mean separation was done by using the least significant difference (LSD). Correlation between yield and yield components was determined by simple linear correlation analysis.

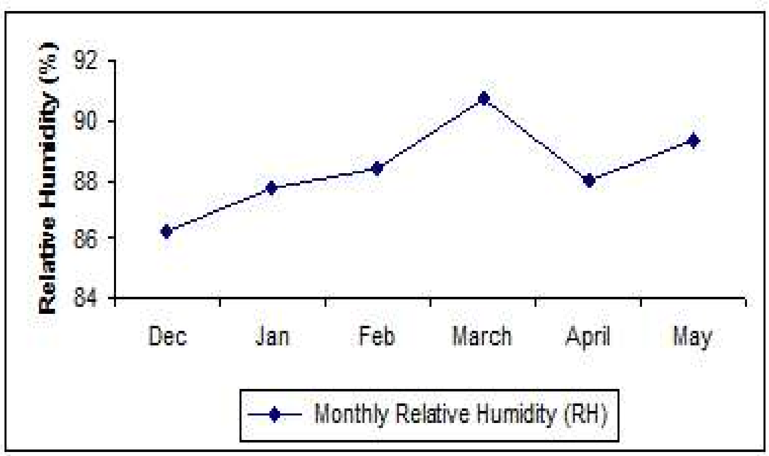
Results

Variation of temperature, rainfall, evaporation and relative humidity over the experimental period

The experiment was conducted during a period of relatively higher temperature and less rainfall. The maximum day temperature ranged between 27.6 – 38.3 ^{o}C and the minimum day temperature ranged between 17 – 27 ^{o}C while the daily mean temperature ranged between 23.5 - 30.4 ^{o}C. Since the experimental period was relatively rain free, daily rainfall varied between the minimum of 0 mm and maximum of 592 mm. Relative humidity varied between 77% - 98% over the experimental period, while pan evaporation rate varied from 0.1 – 13.14 mm day^{-1}. Variations of monthly rainfall and monthly means of temperature, relative humidity and pan evaporation are given in Figure 1.


Temperature (°C)
29.5
29
28.5
28
27.5
27
26.5
26
25.5
Dec
Jan
Feb
March
April
May
Monthly Mean Temperature


Rainfall (mm)
40
30
20
10
0
1
2
3
4
5
6
Monthly Rainfall


Relative Humidity (%)
92
90
88
86
84
Dec
Jan
Feb
March
April
May
Monthly Relative Humidity (RH)

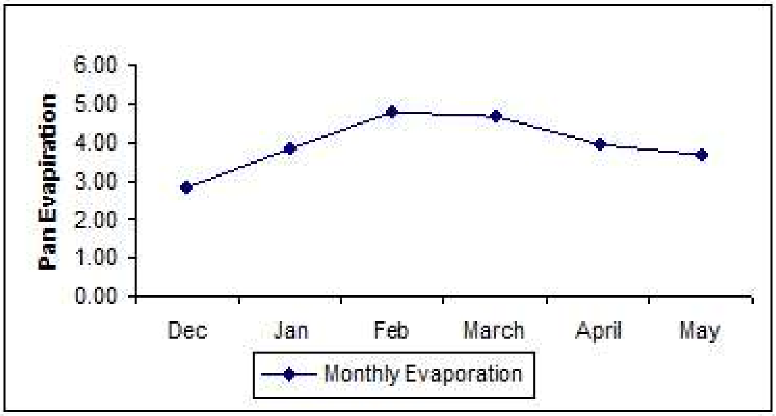


Figure 1: Variation of monthly mean temperature (a), rainfall (b),relative humidity (c), and pan evaporation (d) over the experimental period. The plants were sown in December 2006 and harvested till May 2007.Leaf area per plant

Effects of water stress at the vegetative stage

Water potential

Plant water potential varied significantly between water regimes (p=0.001). However, the variety x water regime interaction and the variety effect were not significant at p=0.05. In both varieties, plants were well watered during the vegetative stage (WW and WS) had higher water potential than those maintained under water stressed conditions (SW and SS) (Table 03).

Total plant fresh weight

Treatment effects on total plant fresh weight at the vegetative stage was statistically significant (p=0.001). Treatments for both varieties showed high water potential during vegetative stage (WW and WS) and had higher plant fresh weights compared to treatments that showed lower water potential (SW and SS) (Table 03). There was a significant variation in plant fresh weights at vegetative stage (p=0.05) among varieties. In both water regimes, HYW, which had a faster vegetative growth, had a greater biomass at the vegetative stage than CA-8. The variety x water regime interaction was not significant.

Plant height

Statistically significant variation (p<0.0001) was observed for plant height under different water regimes. Similar results were observed for plant fresh weight, plant height in treatments WW and WS, while lower plant heights were observed for SW and SS treatments that experienced water stress during vegetative stage (Table 3). However, no significant varietal variation was observed for plant height at the vegetative stage.

Leaf area per plant

Leaf area was varied significantly between different water regimes for both varieties ($p=0.05$). Similar variation was observed in plant height and plant fresh weight. Leaf area was higher in treatments WW and WS compared to treatments SW and SS that experienced water stress conditions (Table 3). This reveals that greater plant water potential favours greater canopy development of the plant. It is notable that under well-watered conditions, variety HYW had a greater leaf area than CA-8.

Plant dry weight

There was no significant difference among treatments or variety variation ($p=0.05$) for plant dry weight during the vegetative growth period. However, variation of plant dry weight also followed the pattern, which was similar to that of other growth parameters. Accordingly, dry matter production was greater in well watered treatments (WW and WS) for both varieties while it was lower in waters stress treatments (SW and SS) at the vegetative stage. Variety HYW had higher plant dry weights than CA-8 under both well-watered and water-stressed conditions.

Table 3: Variation of water potential and plant growth at the vegetative stage of two Capsicum varieties under four different water regimes

Variety	Water regime	Measurements				
		Water potential(MPa)	Plant fresh weight (g)	Plant dry weight (g)	Leaf area (cm2)	Plant height (cm)
HYW	WW	-1.02 a	9.17 a	1.59 a	182.90 a	22.83 a
	WS	-0.97 a	7.96 ab	1.00 a	157.30 a	21.08 a
	SW	-2.00 b	5.43 bc	0.87 a	71.60 b	17.33 b
	SS	-1.80 b	4.37 c	0.83 a	78.23 b	16.17 b
CA-8	WW	-1.03 a	7.04 a	1.09 a	132.60 a	24.25 a
	WS	-0.88 a	7.06 a	0.97 a	146.30 a	22.00 a
	SW	-1.66 b	2.94 b	0.56 b	70.40 b	16.17 b
	SS	-1.50 b	3.98 b	0.74 ab	85.40 b	15.83 b

For each variety, treatment means with the same letter are not significantly different at $p=0.05$. Table 01 for a description of the water regimes.

Effects of water stress at the reproductive stage

Water potential

Plant water potential measurements taken at the reproductive stage showed significant differences among treatments ($p<0.0001$). Plants that were well watered during the reproductive stage (WW and SW) had higher water potential values compared to plants subjected to water stress during the reproductive stage (WS and SS). However, there was no significant variety or variety × treatment interaction for water potential during reproductive stage (Table 4).

Total plant fresh weight

Significant effects among treatments ($p<0.0001$) were observed for total plant fresh weight taken at the reproductive stage. In both varieties, the highest plant fresh weight was observed in the treatment that received well watered conditions during both vegetative and reproductive stages (WW) while lowest was with plants subjected to water stress during both stages (SS) (Table 4). Treatments WS and SW, that experienced water stress during reproductive and vegetative stages respectively had total plant fresh weights in between WW and SS treatments. Among WS and SW, the treatment that received well watered conditions during the vegetative stage had greater total biomass than plants that received well watered conditions during the reproductive stage (SW).

Leaf Area per plant

Treatment ($p=0.0005$), variety ($p=0.01$) and treatment × variety interaction ($p=0.05$) effects were significant for leaf area measurements taken at the reproductive stage. Since variety CA-8 was growing in to larger plants as compared to variety HYW, CA-8 had greater leaf area than HYW for each water regime. Plants subjected to well watered conditions in both vegetative and reproductive stages (WW) had the highest leaf area and the lowest leaf area was in plants subjected to water stress during both stages (SS). In all treatments, except SS, CA-8 had a greater leaf area per plant than the respective treatment in HYW (Table 4).

Plant height

Plant height at the reproductive stage also showed significant treatment differences ($p=0.001$). Plants subjected to well watered conditions during the whole period had the tallest plants. In both varieties, plant height showed a decreasing trend for treatments WW, WS, SW and SS respectively (Table 4). Significant varietal variation was also observed ($p<0.0001$) for plant height as the variety CA-8 was taller than HYW, under all water regimes. In addition, variety x water regime interaction was also significant (p=0.05).

Plant dry weight

Statistically significant (p=0.001) treatment differences were observed for total dry weight per plant at the reproductive stage (Table 4). In both varieties, plants which were well watered during the vegetative stage had greater plant dry weights than those that were water stressed during vegetative stage (SW and SS).

Table 4: Variation of water potential and plant growth at the reproductive stage of two Capsicum varieties under four different water regimes

Variety	Measurements					
	Water regimes	Water potential (MPa)	Plant fresh weight (g)	Plant dry weight (g)	Leaf area (cm^2)	Plant height (cm)
HYW	WW	-0.78^{a}	52.30^{a}	7.69^{a}	404.86^{a}	33.67^{a}
	WS	-1.47^{b}	40.73^{b}	6.66^{a}	373.53^{a}	30.17^{b}
	SW	-0.92^{a}	32.17^{bc}	4.59^{ab}	401.22^{a}	28.83^{bc}
	SS	-1.35^{b}	17.17^{c}	3.01^{b}	229.22^{a}	26.00^{c}
CA-8	WW	-0.82^{a}	69.10^{a}	11.08^{a}	978.92^{a}	56.33^{a}
	WS	-1.50^{b}	39.70^{b}	7.64^{b}	501.60^{b}	47.50^{ab}
	SW	-0.80^{a}	24.56^{bc}	4.17^{b}	435.19^{b}	38.83^{bc}
	SS	-1.52^{b}	16.10^{c}	4.24^{b}	230.32^{b}	34.50^{c}

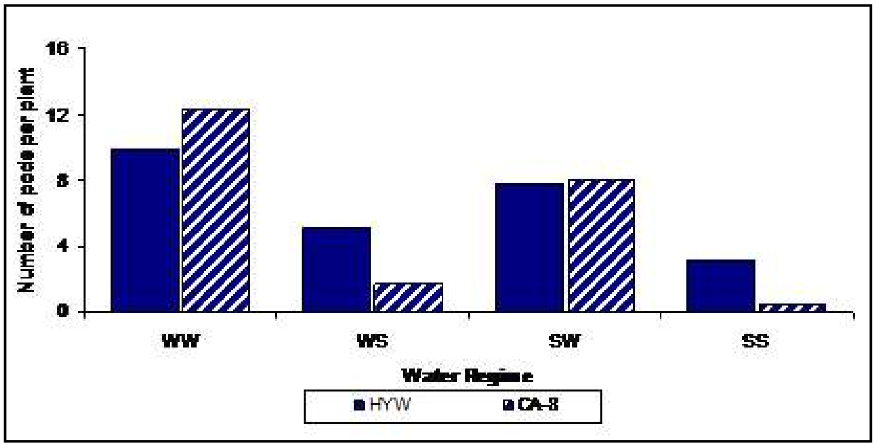
For each variety, treatment means with the same letter are not significantly different at p=0.05. Table 01 for a description of the water regimes.

Effects of water stress on yield

Yield and yield components

Pod yield and the number of pods per plant showed significant ($p<0.05$) variation between treatments (Figure 2). However individual pod weight did not show significant variation between treatments. This indicates that the yield reduction under water stress was mainly due to the reduction of pod number per plant than a reduction of the individual pod weight.

Varietal effect ($p<0.0001$) and the variety × treatment interaction effect (p=0.05) on yield were significant. Within each treatment combination, HYW had higher total pod yield than CA-8. Plants that received well watered condition at both vegetative and reproductive stages (WW) gave the highest yield for both varieties, with 3.32 and 1.27 mt/ha for HYW and CA-8 respectively. In both varieties, plants that were subjected to water stress in both vegetative and reproductive stages (SS) gave the lowest yield (Figure 2). In this treatment, the percentage yield reduction was substantially greater in CA-8 as compared to HYW (Table 5). Percentage yield reductions in WS and SW treatments showed that for both varieties, water stress during the reproductive stage caused a greater yield reduction than water stress during the vegetative stage. Here also, CA-8 showed greater yield reductions that HYW.



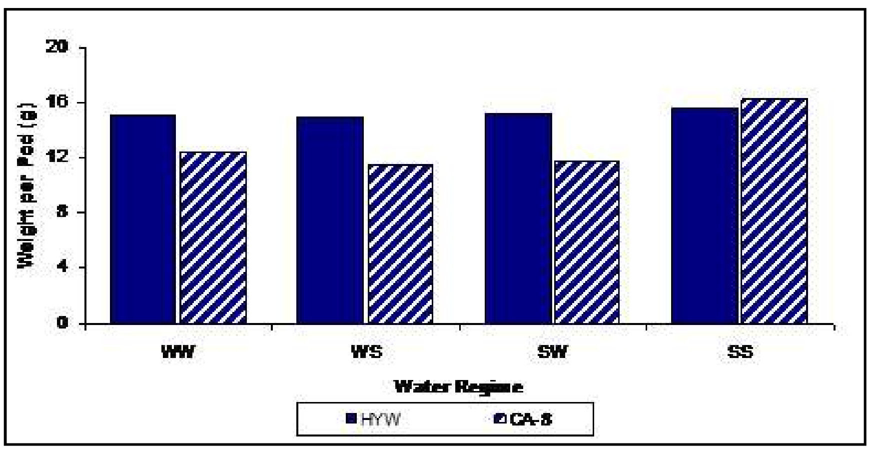


Figure 2: Variation of pods per plant (a) and weight per pod (b) of two varieties of Capsicum under different water regimesWithin each variety, means with the same letter are not significantly different Table 01 for a description of the water regimes.

Table 5: Variation of pod yield and percentage yield reduction of two Capsicum varieties under four different water regimes

Variety	Water regime	Total pod yield (mt/ha)	Percentage yield reduction (%)
HYW	WW	3.32 ^{a}	0
	WS	1.69 ^{ab}	49
	SW	2.61 ^{ab}	21
	SS	1.12 ^{b}	66
CA-8	WW	1.27 ^{a}	0
	WS	0.17 ^{c}	87
	SW	0.78 ^{b}	39
	SS	0.06 ^{c}	95

Harvest Index (HI)

Variety, treatment and treatment × variety interaction effects on Harvest Index were significant at p=0.01 (Table 6). Under all water regimes, HYW had the higher HI than CA-8. There was a clear difference between the two varieties in the response of their respective HI to the different water regimes. In CA-8, the two treatments which experienced water stress at the reproductive stage (WS and SS) showed significant reductions in HI as compared to the other two. In contrast, in HYW, the two corresponding treatments (WS and SS) also had substantially higher HI. This was mainly due to their lower vegetative growth and greater pod growth in comparison to the two corresponding treatments of CA-8.

Correlation analysis

Pod yield had significant positive correlations with pod number ($r^2 = 0.64$ with p=0.001) and individual pod weight ($r^2 = 0.50$ with p =0.05). Among these yield components, number of pods per plant had greater impact on pod yield than the individual pod weight under water stress. In addition pod yield had a significant correlation ($r^2 = 0.44$ with p =0.05) with total plant dry matter at reproductive stage.

Effects of water stress on Root:Shoot ratio (RSR)

Root:shoot ratio (RSR) showed significant variation between water regimes (p=0.05) at the vegetative stage, with the SS treatment in both varieties having greater RSR than the rest (Table 7). At the reproductive stage, although the treatment effects on RSR were not significant, there was significant varietal variation (p=0.01). Under all water regimes, CA-8 had greater RSR than HYW. The water regime x variety interaction was not significant at both stages.

Table 6: Variation of pod yield, total plant fresh weight, vegetative fresh weight and Harvest Index (HI) of two Capsicums varieties under four different water regimes.

Variety	Water regimes	Pod yield per plant (g)	Vegetative fresh Weight (g)	Total plant fresh	HI
HYW	WW	149.37 [a]	92.65 [a]	242.02 [a]	0.62 [a]
	WS	76.38 [b]	79.02 [b]	155.40 [b]	0.49 [b]
	SW	117.67 [a]	105.95 [a]	223.62 [a]	0.53 [b]
	SS	50.38 [b]	46.03 [b]	96.41 [b]	0.52 [b]
CA-8	WW	152.59 [a]	194.69 [a]	347.28 [a]	0.44 [a]
	WS	20.33 [c]	140.79 [b]	161.12 [b]	0.13 [b]
	SW	93.52 [b]	151.96 [b]	245.48 [a]	0.38 [a]
	SS	7.21 [d]	115.14 [c]	122.35 [b]	0.06 [b]

For each variety, treatment means with the same letter are not significantly different at p=0.05. Table 01 for a description of the water regimes.

Table 7: Variation of root:shoot ratio at different growth stages of two Capsicum varieties under different water regimes.

Variety	Water regime	Root: shoot ratio	
		Vegetative stage	Reproductive stage
HYW	WW	0.3128 [b]	0.1467 [a]
	WS	0.3204 [b]	0.1133 [a]
	SW	0.2744 [b]	0.1767 [a]
	SS	0.4631 [a]	0.2067 [a]
CA-8	WW	0.3086 [b]	0.2733 [a]
	WS	0.3980 [b]	0.2167 [a]
	SW	0.3458 [b]	0.2467 [a]
	SS	0.5736 [a]	0.2500 [a]

For each variety, treatment means with the same letter are not significantly different at p=0.05. Table 01 for a description of the water regimes.

Discussion

The present experiment quantified the growth and yield responses of two capsicum varieties, HYW and CA-8 to water stress imposed during vegetative and reproductive stages. The results on vegetative growth parameters such as plant fresh and dry weights and leaf areas showed that water stress during the vegetative stage suppressed vegetative growth. Although water stress during the reproductive stage also reduced vegetative growth, this reduction was not as great as that caused by water stress during the vegetative stage, especially if the plants had received enough water during the vegetative stage. A clear varietal difference was observed in the response of vegetative growth to water stress, with CA-8 growing appreciably bigger plants under water stress with greater fresh and dry weights and leaf area (Table 4).

The response to different water regimes of reproductive growth, measured in terms of pod yield and yield components, was different to that of vegetative growth. Here, a water stress during the reproductive stage caused significant reductions in pod yield, primarily through reductions in pod numbers caused most probably by reduced flower numbers. The two varieties showed a clear difference in their yield reductions in response to water stress, with CA-8 showing substantially greater reductions than HYW. Consequently, the harvest index of CA-8 under water stress during the reproductive stage was substantially lower than that of HYW in the corresponding treatments (WS and SS). Meanwhile, the lower vegetative growth of HYW enabled to produce a comparatively greater yield even under stress during the reproductive stage because it was able to partition a greater amount of assimilates to pods.

Literature has shown that many physiological processes responsible for growth and yield formation of annual crops are affected adversely when the available water in the soil decrease below a threshold value (Turner and Kramer 1980; Taylor et al., 1983; Jones 1992; Smith and Griffiths 1993). This was shown in this study, with the observed reductions in plant water potential which probably triggered the reductions of leaf area, dry matter production and yield formation.

It was suggested widely in literature that greater rooting ability confers drought resistance (Jordan et al., 1983; Blum 1989; Ingram et al., 1994). In the present study, the greater root:shoot ratio of CA-8 may have enabled it to develop a greater vegetative biomass under water stress. However, this led to lower pod yields. Therefore, in the present study, greater rooting ability did not result in a yield advantage under water-limited conditions. However, it should be noted that the present experiment was carried out as a pot experiment where root growth may be restricted. In a field experiment, the greater rooting ability of CA-8 might give it an advantage because it would have access to a greater pool of soil water. However, whether greater rooting ability would result in a yield advantage or not would depend on how the variety uses the additional water that is available to it. If it uses the additional water for greater vegetative growth, a yield advantage under water stress would not occur.

Conclusion

The present study showed that water stress reduced plant growth and yield significantly in both HYW and CA-8. However yield reduction under water stress was greater in CA-8 than HYW (95% and 66% respectively). Water stress during vegetative stage decreased canopy development and dry matter production significantly. However, water stress during reproductive stage had a greater impact on yield reduction rather on canopy development and dry matter production.

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