

# Effects of Water Stress and Plant Density on Cotton (*Gossypium hirsutum* L.) Cultivars Differing in Maturity and Seed Size: I. Yield Components and Fiber Quality Parameters

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**Abstract** – To achieve maximum cotton yield, the combination of genotype, environmental conditions and appropriate management practices should be optimized. Field experiments were conducted in the Aegean region of Turkey during 2008 and 2009 to observe the responses of three cotton cultivars differing in maturity and seed size to deficit water stress under different plant densities. Although plant compensation through monopodial bolls and outer position bolls was seen in some cases, at a plant population of 6.2 plants m<sup>-2</sup> yields were reduced in both years regardless of irrigation levels. Deficit irrigation inversely affected lint yield, yield components, and fiber quality for all cotton cultivars. It is interesting to note that yield, and yield components in this investigation differed greatly between M-2005 (late-maturing and large-seeded cultivar), and Carmen (late-maturing and smaller-seeded cultivar) and Flash (early-maturing and smaller-seeded). Deficit water stress decreased lint yield and boll number per m<sup>2</sup>, lint mass per seed for M-2005 more than Carmen and Flash. Under deficit irrigation, Carmen produced significantly higher yield than Flash in year one, but both cultivars produced similar lint yields in year two. These results suggest that late-maturing and also small-seeded cultivar would be preferable under deficit irrigation, and that optimal plant population was higher under water deficit condition, and that the response to deficit irrigation stress was controlled more by genotype and to a lesser extent by management of plant density.

**Keywords** – Cotton, Deficit Water Stress, Plant Density, Lint Yield.

## I. INTRODUCTION

Yield is determined by the combination of genotype, environmental conditions and appropriate management practices. Among the environmental stresses, water deficit has the main adverse effect on cotton yield around the world since almost 50% of the cotton production area is not irrigated [1]. Although cotton is considered a drought tolerant crop, it is an excellent candidate for irrigation. Cotton yield is dependent upon the production and the retention of bolls, and both can be decreased by water

stress [2]. Under water stress, decrease in seed cotton yield is primarily due to the reduction in number of bolls and boll weight [3], [4], [5]. Water stress affects lint quality in numerous ways, especially during the fiber elongation period, which result in a decrease in fiber length and causes fiber immaturity [4].

Optimal plant population for high yield and fiber quality in upland cotton has been studied by several researchers for last century. However, the results of these studies were inconsistent. Several researchers have reported no significant difference in total seed cotton yield due to changes in plant density [6], while others have observed yield decreases with excessive or deficient plant populations [7]. Another factors affecting cotton cultivar response to water deficit are maturity group and seed size. Under conditions where soil moisture is less predictable, phenological plasticity or indeterminate growth may be more beneficial than earliness [8]. [9] showed that positive associations between crop maturity and lint yield suggested that later-maturing cultivars had a higher yield potential under dryland conditions. In terms of seed size, [10] suggested cultivars with medium to small bolls might adjust more rapidly to adverse environmental conditions. Since smaller-seeded cultivars produce smaller but more bolls per unit land area, each boll would require not only less energy but aborted of a boll wasted less energy, and small boll would require less energy to replace previously aborted bolls [11].

The effect of water deficit, plant density, cotton cultivars and their single influence on cotton yield have been well studied. Most studies only documented how either water (moisture) deficit or plant density affect yield and yield components, or fiber quality parameters. However, none of the previous studies attempts to determine response of cotton cultivars differing in maturity and seed size to water stress under different plant density. Therefore, the objective of this research was to evaluate the responses of cotton cultivars differing in maturity and seed size to deficit water stress under different plant densities.

## II. MATERIALS AND METHODS

Field experiments were conducted at the Adnan Menderes University, Agriculture Faculty Experimental Fields Aydin-Turkey (37° 51' N latitude, 27° 51' E longitude) from 2008 to 2009. Upland cotton cultivars used for experiments are Carmen, (late-maturing and small seeded), Menderes-2005 (late-maturing and large-seeded) and Flash (early-maturing and small-seeded). Cotton (Carmen, Menderes-2005, and Flash) was seeded on 7 May 2008 and 13 May 2009, and approximately three week after planting hand thinned to in-row plant spacing of 23 cm for 6.2 plants m<sup>-2</sup>, 18 cm for 7.9 plants m<sup>-2</sup>, 13 cm for 10.9 plants m<sup>-2</sup> and 8 cm for 17.8 plants m<sup>-2</sup> in each row, respectively. A split-split plot design with four replications was used for the study. The main plot was irrigation treatments (full irrigated and water stressed = deficit irrigated), which were split to three cotton cultivars (Carmen, Menderes-2005, and Flash), which were split to plant densities. Each sub-subplot contained four rows of cotton, 12 m long with an inter-row spacing of 0.70 m. A compound fertilizer (15% N, 15% K 15% P composite) was applied at a rate of 60 kg ha<sup>-1</sup> pure N, P and K at planting. The required remaining portion of nitrogen was followed by 82 kg ha<sup>-1</sup> as ammonium nitrate 33% before first irrigation. In the study, two irrigation treatments (full irrigated and water stressed) were evaluated in trials. The irrigation treatments were based on replenishment of soil water depletion. The control treatment (full irrigation) was designated to receive 100% and water stress applied plots received 50 % replenishment of soil water depletion. In 2008, the irrigated plots (the control = full irrigation) received four furrow irrigations for a total 412 mm. Three furrow irrigations totaling 309 mm were applied to the irrigated plots (the control = full irrigation) in 2009. In water stress treatment irrigation was applied at the rates of 50 % of control treatment (full irrigation) on the same day for both years. Soil water level was monitored by using the gravimetric method in the plots. The amount of soil moisture in 1.2 m depth was used to initiate irrigation. The SAS GLM procedure (SAS Institute, 2000) [12] was used to fit the linear model including main effects and all two- and three-way interactions and the test option in GLM procedure was utilized to indicate correct error terms in

the analyses. After significant effects were identified, differences between least square means were considered significant at 0.05 based on Least Significant Difference (LSD).

## III. RESULT AND DISCUSSION

Low (6.2 plants m<sup>-2</sup>) and high (17.8 plants m<sup>-2</sup>) plant densities produced similar number of bolls at per unit area under full and deficit irrigation (Table I). Thus, there was consistent compensation among plants that resulted in the same number of bolls being produced per unit area when plant density changed regardless of irrigation level. These results contrast with those of [13] and [11], who reported that increasing plant density increased boll number ha<sup>-1</sup> but similar to the results of [14]. Significant irrigation x cultivar interaction indicate that the response to irrigation level was controlled by cultivar to a greater extent than plant density. In both years, deficit irrigation affected more M-2005 than Carmen and Flash cotton cultivars. Across the average plant density and years, deficit irrigation decreased 35.45% total boll number per unit area of M-2005 while the reduction ratio was 21.7% for Flash; and 9.6% for Carmen. This result shows that late-maturing and small-seeded cultivars would be more tolerant to deficit water stress condition than late-maturing and large-seeded cultivars.

Deficit irrigation decreased boll mass 10.5% in 2008 and 12.5% in 2009 (Table I). Reduction in boll weight may be attributed to decreased leaf area expansion [13] and photosynthetic production [15] due to water stress. This result is similar to [13] and [5], whereas [16] found no difference in boll mass between soil moisture regimes. With increasing plant density, boll number per plant (data do not shown here) and boll lint mass decreased. Several studies have concluded that boll size is inversely related to population density [6], [14]. The results reported here would be in agreement with [17] who found that limited fruit removal resulted in increased vegetative growth and reduced boll weight. [6] reported that decreased boll set and weight from increased population density may result from the combined effects of excessive leaf area index (LAI), reduced photosynthetic photon flux density (PPFD) efficiency, and reduced mean net assimilation rate (NAR).

Table I: Number of total bolls per square meter and lint weight per boll in different plant density and irrigation level studies in 2008 and 2009.

Cultivars	Density Plant m <sup>-2</sup>	Boll number				Lint weight			
		2008		2009		2008		2009	
		I	WS	I	WS	I	WS	I	WS
		bolls m <sup>-2</sup>				g boll <sup>-1</sup>			
Carmen	6.2	102.4	99.8	123.6	98.6	2.58	2.30	2.86	2.48
	7.9	121.4	120.8	104.9	94.8	2.73	2.41	2.77	2.59
	10.9	97.8	97.3	123.1	82.9	2.59	2.46	2.55	2.35
	17.8	110.4	119.6	114.7	103.1	2.60	2.37	2.68	2.14
Mean		108.0	109.4	116.6	94.9	2.63	2.38	2.72	2.39
M-2005	6.2	97.9	72.8	104.8	68.9	2.29	1.99	2.95	2.48
	7.9	87.0	63.7	110.1	65.5	2.13	1.93	2.75	2.59
	10.9	102.2	50.3	112.1	64.0	2.34	1.87	2.92	2.53

	17.8	80.9	59.8	114.3	75.4	2.17	1.81	2.70	2.39
Mean		92.0	61.7	110.3	68.5	2.23	1.90	2.83	2.50
Flash	6.2	128.4	116.1	149.5	102.8	2.05	1.81	2.53	2.11
	7.9	138.1	122.8	139.5	89.9	2.21	2.24	2.75	2.41
	10.9	112.1	107.9	134.3	90.1	2.32	2.12	2.52	2.14
	17.8	133.9	116.1	137.5	94.2	2.45	2.14	2.72	2.44
Mean		128.1	115.8	140.2	94.2	2.26	2.08	2.63	2.27
Overall mean		109.0	95.6	122.4	85.7	2.37	2.12	2.73	2.39
Source of variation		P > F							
Irrigation (I)		<0.0001		<0.0001		<0.0001	0.24 <sup>§</sup>	<0.0001	0.22
Cultivars (C)		<0.0001		<0.0001		<0.0001	0.17	<0.0001	0.15
Plant Density (D)		0.0005		0.0173	5.43	0.0088	0.10	<0.0001	0.09
I x C		<0.0001	15.96 <sup>*</sup>	<0.0001	13.30	0.2078	ns <sup>‡</sup>	0.9065	ns
I x D		0.3602	ns <sup>‡</sup>	0.1211	ns	0.5402	ns	0.1756	ns
C x D		0.0011	11.31	0.1495	ns	0.0552	ns	0.1371	ns
I x C x D		0.0445	15.99	0.1548	ns	0.4526	ns	0.3556	ns

\*: The least significant difference test values at 0.05 probability level.

‡: Not significantly different at  $P < 0.05$ .

Lint percentage was not affected by plant density and the response to irrigation level was inconsistent (Table 2). While no differences were observed in 2008, lint percentage decreased from 41.4% to 39.9% as irrigation level increased during the 2009 growing season. This result could be attributed to the decline in ratio of seed mass under deficit irrigation. Previous studies reported that the delay in maturity and increased seed weight would result in decreasing lint percentage as irrigation increased [16], [18]. In both years, large-seeded cultivar, M-2005, had less lint percentage than small-seeded cultivars, Carmen and Flash, due to the high seed mass.

In the current study, lint yields were the highest with populations of 7.9, 10.9 and 17.8 plants  $m^{-2}$  compared to 6.2 plants  $m^{-2}$  under both irrigation regimes and years (Table II). Because stress conditions reduce plant size, it has been suggested that low-yield environments would favor high plant density over low plant density [19]. Water deficit stress decreased the averaged lint yield 30.9% in 2008, and 25.8% in 2009. A number of previous studies have demonstrated a decrease in seed cotton yield under water-stress conditions [5], [16]. Water stress resulted in decreased lint yield by affecting yield components. Different researchers reported that the yield produced by a cotton cultivar is determined by the number of bolls per

unit area, total seed surface area per unit area, the number of lint fibers per unit seed surface area, the average weight per fiber, and the number of fibers per square meter of land [20], [21]. Thus, cotton yield is integrated through a combination of yield components. Significant irrigation x cultivar interaction in both years indicated that the response of cotton cultivar to water stress varied. Water deficit stress decreased lint yield 16.7% (Carmen), 50.8% (M-2005), 31.4% (Flash) in 2008, and 15.0% (Carmen), 42.8% (M-2005), 24.0% (Flash) in 2009 respectively. The M-2005 cotton cultivar in this investigation produced fewer bolls per unit land area, low boll lint weight and lint percentage than Carmen and Flash under water deficit stress. The declining ratio of basic yield components for M-2005 is found to be more affected by deficit water stress than Carmen and Flash. Therefore, M-2005, the larger-seeded cultivar, is much more sensitive to water stress due to the high energy requirement for total seed mass production. The present results support those of [10] who reported that smaller-seeded cultivars requires less energy to produce each boll, thus when the stress was released (e.g., through irrigation), less energy would be required to replace previously aborted bolls. These results indicate that late-maturing and small-seeded cotton cultivars would be more tolerant to water deficit stress.

Table II: Lint percentage and lint yield in different plant density and irrigation level studies in 2008 and 2009.

Cultivars	Density Plant $m^{-2}$	Lint percentage				Lint yield			
		2008		2009		2008		2009	
		I	WS	I	WS	I	WS	I	WS
		%				kg $ha^{-1}$			
Carmen	6.2	39.7	39.7	40.0	41.8	1464	1299	2269	2076
	7.9	40.1	40.3	39.6	42.1	1874	1269	2424	2016
	10.9	39.1	39.8	39.5	41.6	1774	1499	2464	2014
	17.8	39.8	39.8	40.2	41.2	1950	1812	2420	2029
Mean		39.6	39.9	39.9	41.7	1765	1470	2394	2034
M-2005	6.2	35.6	36.8	39.6	39.5	1056	574	1770	845
	7.9	35.8	37.0	37.5	39.4	1196	545	1879	933
	10.9	36.9	37.7	38.3	38.9	1326	603	1864	1049

	17.8	37.6	37.1	38.5	39.4	1334	696	1687	1290
Mean		36.3	37.2	38.4	39.3	1228	604	1800	1029
Flash	6.2	40.1	39.8	41.8	43.4	1605	973	2559	1744
	7.9	39.9	40.1	40.8	42.8	1770	1373	2704	2228
	10.9	39.7	40.1	41.5	42.9	1824	1274	2736	1951
	17.8	39.6	39.3	41.9	43.1	1835	1209	2800	2279
Mean		39.8	39.8	41.5	43.1	1759	1207	2700	2051
Overall mean		38.6	38.9	39.9	41.4	1584	1094	2298	1704
Source of variation	P > F								
Irrigation (I)	0.1100	ns	<0.0001	1.29	<0.0001		<0.0001		
Cultivars (C)	<0.0001	0.71*	<0.0001	0.91	<0.0001		<0.0001		
Plant Density (D)	0.4925	ns†	0.1383	ns	<0.0001		0.0187		
I x C	0.0512	ns	0.1327	ns	<0.0001	141	0.0023	318	
I x D	0.5674	ns	0.2418	ns	0.1596	ns	0.2459	ns	
C x D	0.0195	0.71	0.6312	ns	<0.0001	100	0.4247	ns	
I x C x D	0.8009	ns	0.8277	ns	0.0002	141	0.2065	ns	

\*: The least significant difference test values at 0.05 probability level.

†: Not significantly different at  $P < 0.05$ .

Micronaire was affected by cultivars in both years, but was not significantly impacted by either irrigation regimes or plant density in both years. Varying the plant density did not affect micronaire. These results also agree with those reported by [7], [14] and [22]. Fiber length was unaffected by plant density yet greatly influenced by irrigation and cultivars as main factors, and by irrigation x cultivars interaction during experiment (Table III). [7], [14], [19] and [22] also reported that plant population had no effect on fiber length. Averaged across cultivars, fiber length was shortened 3.4% and 4.5% in response to soil moisture deficits in the first and second year of experiment, respectively. Our results corroborate those of [5] and [18] who reported that as irrigation ratio increased fiber length increased. A significant cultivar x irrigation level interaction was detected for fiber length in both years. In 2008, Carmen and M-2005 cultivars had longer fiber than Flash, and in 2009, M-2005 produced longer fiber than both cultivars under full irrigation. However, when plants received deficit irrigation difference in fiber length among cultivars was not significant in either of the years. The effect of plant density on fiber strength was much more evident when plants received full irrigation, and plants produced stronger fiber under low plant density. [7], [16] have reported that fiber strength was not

influenced by plant population, while [23] reported a reduction in fiber strength with a plant population of 3.6 plants  $m^{-2}$  compared to 9.0-21.5 plants  $m^{-2}$ . Deficit irrigation resulted in 3.7% weaker fiber in 2008 but had no effect on fiber strength in 2009. This response is in contrast to the results of [24] who reported that fiber strength improved with a decrease in water application. [25] found that fiber strength was well correlated with soil water, which is similar to the findings of this study.

The tendency in both years of the study was that fiber quality parameters including micronaire, fiber length and strength were not adversely affected by plant population density (Table III). A significant cultivar x irrigation treatment interaction for fiber length and strength showed that both characters are primarily a genetic trait and to a greater extent controlled by genotype as reported in previous studies [5]. Among cultivars only M-2005 had significantly reduced fiber length and strength under water deficit, reduction as a percent of full irrigation values across the years were 6.53% for fiber length and 4.17% for fiber strength. Although M-2005 had the highest reduction ratio in fiber length and strength, this cultivar produced the equal fiber length and strength with other two cotton cultivars under deficit water stress due to having large seed mass.

Table III: Micronaire, fiber length and fiber strength in different plant density and irrigation level studies in 2008 and 2009.

Cultivars	Density	Micronaire				Fiber length				Fiber strength					
		2008		2009		2008		2009		2008		2009			
		I	WS	I	WS	I	WS	I	WS	I	WS	I	WS		
	Plant $m^{-2}$	mm												g $tex^{-1}$	
Carmen	6.2	4.9	4.6	4.9	4.9	29.8	28.9	30.6	29.8	32.5	32.1	36.1	34.8		
	7.9	4.8	4.6	4.8	4.9	29.7	28.6	30.0	30.0	33.2	32.4	34.9	34.2		
	10.9	4.9	4.7	4.9	4.9	29.7	29.4	31.0	29.6	32.6	32.8	35.1	34.5		
	17.8	4.9	4.6	4.9	4.8	30.1	29.5	31.1	30.1	33.2	33.9	36.0	36.0		
Mean		4.9	4.7	4.9	4.9	29.8	29.1	30.7	29.9	32.9	32.8	35.5	34.7		
M-2005	6.2	4.4	4.3	5.1	5.0	31.1	28.7	31.3	28.8	35.4	31.7	36.1	34.9		

	7.9	4.3	4.5	4.9	4.9	30.9	28.8	32.3	29.4	34.4	32.1	35.8	34.9
	10.9	4.5	4.5	4.8	4.9	29.8	28.4	32.1	30.0	34.2	33.1	37.0	36.9
	17.8	4.6	4.5	4.7	4.9	30.4	29.2	31.5	29.7	34.3	31.0	35.6	36.4
Mean		4.4	4.4	4.9	4.9	30.6	28.8	31.8	29.5	34.6	31.9	36.1	35.8
Flash	6.2	4.9	4.5	5.1	5.2	28.9	28.3	30.4	28.9	32.6	30.1	33.5	33.5
	7.9	4.7	4.7	4.9	5.1	28.2	27.6	30.8	29.5	30.6	29.8	33.3	31.9
	10.9	4.5	4.5	5.1	5.1	29.2	28.6	30.6	29.8	31.2	30.6	32.7	32.3
	17.8	4.5	4.2	5.1	5.1	28.8	28.5	29.9	29.4	30.7	30.8	32.7	33.3
Mean		4.6	4.5	4.8	5.1	28.8	28.3	30.4	29.4	31.3	30.3	33.1	32.7
Overall mean		4.6	4.5	4.9	5.0	29.7	28.7	30.9	29.6	33.3	31.7	34.9	34.5
Source of variation	P > F												
Irrigation (I)	0.1856	ns*	0.1043	ns	<0.0001	<0.0001	<0.0001	<0.0001	0.1609	ns			
Cultivars (C)	<0.0001	0.31‡	0.0024	0.19	<0.0001	0.0046	<0.0001	<0.0001	<0.0001	1.55			
Plant Density (D)	0.3340	ns	0.1820	ns	0.1611	ns	0.1630	ns	0.0006	0.2554	ns		
I x C	0.7975	ns	0.8214	ns	<0.0001	1.06	0.0016	1.16	0.0005	2.22	0.8998	ns	
I x D	0.6271	ns	0.8868	ns	0.1322	ns	0.7944	ns	0.4975	ns	0.3664	ns	
C x D	0.2797	ns	0.8686	ns	0.1630	ns	0.3765	ns	0.0019	1.57	0.2677	ns	
I x C x D	0.4743	ns	0.8811	ns	0.6107	ns	0.4261	ns	0.1228	ns	0.9674	ns	

\*: The least significant difference test values at 0.05 probability level.

‡: Not significantly different at  $P < 0.05$ .

#### IV. CONCLUSION

Our results show that maximum yields can be obtained with plant densities between 7.9 and 17.8 plants  $m^{-2}$  for full irrigation, and 17.8 plants  $m^{-2}$  for deficit irrigation. Deficit irrigation inversely affected yield, yield components and fiber quality for all cotton cultivars. It is interesting to note that yield, and yield components in this investigation differed greatly between late-maturing and large-seeded cultivar (M-2005), and late- and early-maturing and also small-seeded cultivars (Carmen and Flash). These data showed that late-maturing and also small-seeded cultivar would be preferable under deficit irrigation, since cultivars with small seed are able to produce higher lint yield through the production of more bolls per unit area than large-seeded cultivar.

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