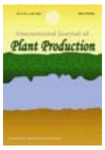

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Lint yield and seed quality response of drip irrigated cotton under various levels of water

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Abstract

Restricted water resources are a limiting factor for irrigation applications throughout the world. The effects of irrigation regimes (amount) on cotton lint yield are known, but there is little information on the effect of irrigation regimes on seed quality of cotton. In this study, the effects of deficit irrigation after the onset of flowering on lint yield and seed quality of cotton (*Gossypium hirsutum* L.) with a drip irrigation system were evaluated during 2006 and 2007 in the northern Iran. After the onset of flowering, four irrigation regimes (0, 40, 70 and 100% of Class A pan evaporation (%PE)) were applied when the cumulative evaporation amount from class A pan reached approximately 40-50 mm. Lint yield showed a quadratic response to %PE and maximum lint yields were achieved with 82 and 91% PE irrigation regimes in 2006 and 2007, respectively and seed quality (based on standard germination and seed vigor tests) increased with a decrease in deficit irrigation. Thus when the amount of applied water was reduced by 30 (70% PE) and 60% (40% PE), decrease in lint yield was about 4 and 14%, respectively. The results of this study showed that irrigation treatments of 40-70% PE would be optimum for lint yield and seed quality production under drip irrigation.

Keywords: Deficit irrigation; Germination; Seed Vigor.

Introduction

It is likely that there will be intense competition for water supplies for crop irrigation, household use, industry, and tourism in the future. This increasing need for crop production for a growing population is causing rapid expansion of irrigation (Hay and Porter, 2006; Gadissa and Chemeda, 2009). Efficient use of irrigation water is becoming increasingly important, and alternative water application methods, such as low pressure sprinkler and drip, may contribute substantially toward making the best use of water for agriculture and improving irrigation efficiency (Srinivas et al., 1989; Mateos et al., 1991; Sezan et al., 2008).

Cotton (*Gossypium hirsutum* L.) is one of the most important fiber-producing plants throughout the world, including Iran. Cotton provides raw material not only for the textile industry but also the feed and oil industries with its seed, rich in both oil (18-24%) and protein (20-40%) (Cetin and Bilgel, 2002). One of the critical problems in cotton production is the amount of irrigation. Excessive irrigation of cotton can lead to increase in vegetative growth, delay maturity, reduce number of open bolls, and decrease the yield, whereas insufficient water can cause an increase in shedding, thus, a decrease in yield (Ertek and Kanber, 2003; Karam et al., 2006; Buttar, et al., 2007). Irrigation therefore is of greater importance for cotton than for most other cultivated plants (Cetin and Bilgel, 2002; Detar, 2008), and the intensity of the operation requires that soil water supply is kept at the optimal level to maximize yield (Sezen et al., 2008).

Water availability may influence not only the interrelationships between seed yield and its components but also the seed quality (Iannucci et al., 2002). Dornbos et al. (1989) and Heatherly (1993) reported that drought stress during the seed filling period in soybean caused significant reductions in seed quality, while Vieira et al. (1991) in soybean, Iannucci et al. (2002) in alfalfa and Ghassemi-Golezani et al. (1997) in maize and sorghum reported that drought stress caused yield reductions, but found no effect on seed quality. Thus, it is important to determine the amount of water in irrigation that optimizes both plant yield and seed quality (Iannucci et al., 2002).

Water is becoming increasingly scarce, creating ever more serious droughts, especially in the Mediterranean region. Therefore, water supply is a major constraint to crop production in the Mediterranean region of Iran (Kazemi, 2000; Sharifan and Hezarjaribi, 2009). The effects of irrigation regimes on yield and yield components of cotton are known, but there is little information on the effect of irrigation regimes on seed quality. Thus, our aim was to evaluate the effects of irrigation regimes on cotton lint yield and seed quality and to determine the level of deficit irrigation that optimizes cotton yield and seed quality.

Materials and Methods

Experimental site

Field experiments were conducted at the Research Station of Cotton, Hashem-Abad, Gorgan, in northern Iran during the growing season of 2006 and 2007. The experimental site is situated in latitude 36° 51′ N, longitude 54° 16′ E and altitude 13.3 m. The area has a typical Mediterranean climate-cool and rainy in winter, hot and dry in summer. The detailed climatic parameters recorded in experimental site are shown in Table 1. Soil properties were determined before the experiment (Table 2).

Experimental design and treatments

Cotton (*Gossypium hirsutum* cv Sepid) was sown on 24 April of 2006 and on 30 April of 2007 into rows (80 cm between rows and 10 cm within the row). The recommended amount of fertilizers was 130 kg/ha N and 70 kg/ha P_2O_5. All the P and half the N was applied before sowing; the other half of the N was top-dressed at flowering. Pest and weed management was applied as required during the growing season, according to local practices performed at the experimental station. Four different irrigation regimes (0, 40, 70 and 100% of Class A pan evaporation (%PE)) were used with three replicates of each treatment in a randomized complete block design. Irrigation started when the first flowers appeared. The number of days from sowing to flowering was 86 d in 2006 and 73 d in 2007, respectively. After the start of flowering, the cotton was irrigated with drip tape (Eurodrip). The drip tape was set on alternating inter-row spaces (1.60 m apart) and tapes have in-line drippers at 30 cm distance. The drippers had a discharge rate of 2 L/h under operation pressure of 1 atm. Two rows of cotton were planted between two drip irrigation lines. Water requirements for the crop were estimated on the basis of the evaporated water, calculated from a Class A pan evaporation (PE). Further irrigations were applied when the cumulative evaporation amount from class A pan reached approximately 40-50 mm.

The plants were harvested by hand picking in each plot 148 and 150 days after sowing in 2006 and 2007, respectively. Mature bolls from each plot were ginned individually, using a roller gin to separation lint and seed. After ginning, the fuzz on the seeds was removed by thorough mixing of seeds with H_2SO_4 (95-97%). Immediately after delinting, the seeds were thoroughly rinsed with deionised water and dried under shade. The seeds were stored in a refrigerator until used.

Table 1. Monthly maximum, minimum and average temperature, average sunshine and rainfall at Gorgan, Iran in 2006 and 2007.

Climatological data	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average or total
2006													
Rainfall (mm)	60.7	16.8	37.9	43.7	26.7	10.0	3.4	0.0	10.3	39.4	147.7	60.4	457
Min. temperature (°C)	0.8	4.9	7.5	12.1	16.1	22.1	24.0	24	20.3	17.5	8.6	4.1	13.5
Max. temperature (°C)	9.3	15.1	18.6	21.1	27.2	33.5	32.5	36.1	30.9	28.2	19.2	12.3	23.8
Avg. temperature (°C)	5.0	10.0	13.0	16.6	21.6	27.8	28.3	30.0	25.6	22.8	13.9	8.2	18.6
Avg. sunshine (h)	4.5	5.4	5.4	5.5	5.5	9.2	6.5	10.6	7.6	5.8	5.7	3.9	6.3
2007													
Rainfall (mm)	22.1	66.0	124.1	31.6	30.4	21.8	4.8	13.3	59.8	1.1	60.5	40.9	476
Min. temperature (°C)	2.6	3.6	6.0	10.6	15.2	21.2	22.6	23.9	20.7	13.9	8.7	3.7	12.8
Max. temperature (°C)	14.6	13.8	15.0	18.9	28.2	31.7	32.6	35.0	32.2	26.6	19.5	13.6	23.5
Avg. temperature (°C)	8.6	8.7	10.5	14.7	21.6	26.5	27.6	29.4	26.4	20.2	14.1	8.6	18.1
Avg. sunshine (h)	6.4	5.1	3.8	3.4	7.9	6.6	6.9	9.7	8.4	7.8	5.4	5.4	6.4

Table 2. Some properties of soil profile in the experimental site.

Depth (cm)	BD[a] (g cm^{-3})	FC[b] (%)	PWP[c] (%)	pH	EC[d] (dSm^{-1})	Organic carbon (%)	Texture
0-30	1.4	33.0	18.5	7.5	0.9	1.2	Silty clay
30-60	1.5	33.3	16.4	7.7	0.7	0.57	Silty clay

[a] BD: Bulk density; [b] FC: Field capacity.
[c] PWP: Permanent wilting point; [d] EC: Electrical conductivity.

Laboratory experiments

The laboratory experiments were carried out at the seed laboratory of the Department of Agronomy, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. The seed quality was evaluated by standard germination and vigor tests in the laboratory following a completely randomized design with four replicates of 50 seeds in all experiments.

Standard germination (SG): seed samples were sown on moistened rolled paper and kept at 25±0.5 °C in the dark. On the twelfth day, normal seedlings were counted.

Seedling growth rate vigor test (SGR): seed samples were seeded as for the SG test and normal seedling length and dry weight were measured after 12 d.

Electrical conductivity vigor test (EC): the test was carried out according to the methodology proposed by Hampton and TeKrony (1995). Seed samples (50 seeds) were weighed, placed into plastic cups with 250 ml of deionised water, and held at 20 °C for 24 h. Conductivity of the leachate was then measured and results were expressed as μS cm^{-1} g^{-1}.

Cool germination vigor test (CG): seed samples were seeded in rolled paper towels following the procedures described for the SG test. The rolls were placed inside plastic bags and kept at 18±0.5 °C in the dark, and germination was assessed eight days after sowing. The percentage of normal seedlings which had a total length of four cm or longer was determined (Hampton and TeKrony, 1995).

Statistical analysis

Data from the field and laboratory experiments were subjected to analysis of variance, and means of treatments were compared using least significant difference (LSD) at 5% levels of probability. Regression analysis was performed to determine the relationship of cotton yield and seed weight with irrigation regimes for each year. The quadratic model was used to quantify the response of lint yield to PE and to estimate maximum lint yield. The PE resulting in a maximum lint yield was calculated from the first derivative of regression model.

Results

Climatic conditions and irrigation treatments

Table 3 shows the temperature and rainfall of growing season in 2006 and 2007. The temperature and rainfall conditions during the two growing season were a little different. Average temperature during the growing season was 26.3 °C in 2006 and 26.4 °C in 2007 and total rainfall was 72 and 82 mm in 2006 and 2007, respectively. Only 16-17% of the rainfall fell in the growing season each year. In accordance with the experimental plan, the cotton was deficit irrigated from onset of flowering to harvesting and number of days from flowering to harvesting was 62 and 72 d in 2006 and 2007, respectively (Table 3). The treatments followed the experimental plan fairly closely with the actual percentage of PE (Table 4).

Table 3. Dates of sowing, dates of flowering, dates of harvesting, amount of rainfall and average temperature from sowing to flowering, flowering to harvesting, and from sowing to harvesting for cotton crop in 2006 and 2007.

	2006	2007
Date of sowing	24 April	30 April
Date of flowering	19 July	12 July
Date of harvesting	19 September	27 September
Amount of rainfall from sowing to flowering (mm)	61.7	54.1
Amount of rainfall from flowering to harvesting (mm)	10.6	28.3
Amount of rainfall from sowing to harvesting (mm)	72.3	82.4
Total annual rainfall (mm)	457	476
Average temperature from sowing to flowering (°C)	24.6	24.4
Average temperature from flowering to harvesting (°C)	28.7	28.4
Average temperature from sowing to harvesting (°C)	26.3	26.4
Average annual temperature (°C)	18.6	18.1

Table 4. Different pan evaporation (PE) based irrigation regimes and water applied plus rainfall for cotton crop in 2006 and 2007.

Irrigation (%PE)	regimes	Water applied for good plant establishment plus rainfall (mm)	Water applied from the onset of flowering to the last irrigation (mm)	Total water applied (mm)
Planned	Actual			
		2006		
100	99	153	314	467
70	69	153	218	371
40	40	153	127	280
0	0	153	0	153
		2007		
100	106	155	295	450
70	71	155	198	353
40	38	155	105	260
0	0	155	0	155

Seed cotton yield and seed weight

According to the results of this two-year study, lint yields and 100 seed weights ranged from 619 to 1329 kg/ha and 9 to 10.6 g, and 605 to 1313 kg/ha and 8 to 9.3 g in 2006 and 2007, respectively. In both years, there were significant effects of irrigation regime on lint yield and seed weight (data not shown).

As seen at Figure 1, lint yield showed quadratic responses to irrigation regime. There were significant increases in the lint yield when water supply was increased progressively from 0 to 70% PE, but there was little increase beyond 70% PE. Calculated from the first derivative of quadratic models, maximum lint yield was achieved with 82 and 91% PE irrigation regimes in 2006 and 2007, respectively.

Relationships between seed weight and irrigation regime are shown in Figure 1. While there was significant linear response between seed weight and irrigation regime in 2006, there was significant quadratic response between them in 2007. Calculated from the first derivative of quadratic models, maximum seed weight was achieved at 100 and 63% PE, in 2006 and 2007, respectively (Figure 1).

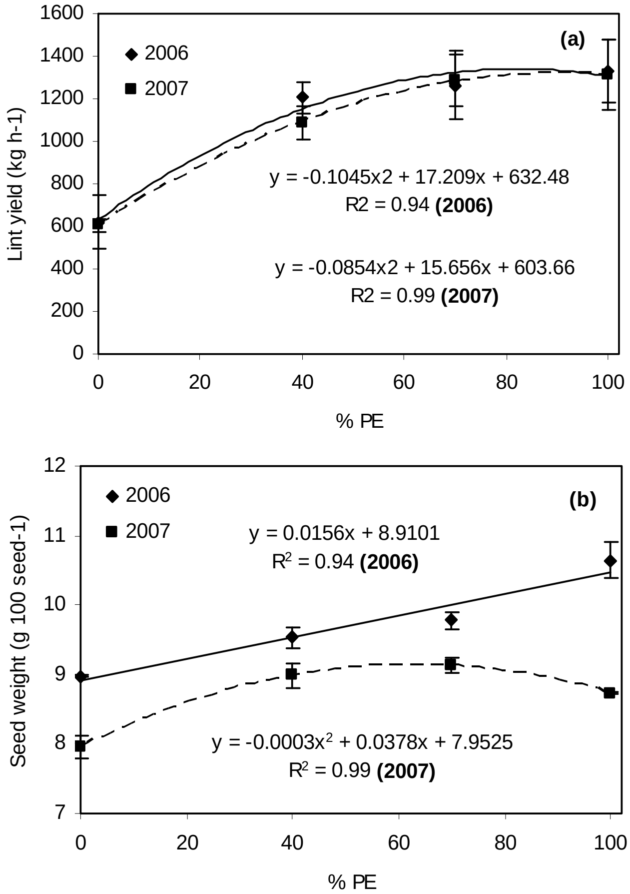

Figure 1. Relationships of cotton lint yield (a) and seed weight (b) with %PE (Pan Evaporation of Class A).

Seed quality

Germination percentage generally decreased with increasing irrigation levels each year. Germination percentage was not significantly affected by irrigation regimes in 2006 but it was significantly affected by irrigation regimes in 2007, and a significant increase in germination percentage occurred between the 0 and 40% PE (Table 5). According to these results, germination percentage was affected by irrigation regimes; that is, the germination percentage was higher in 0% PE treatment and was lower in 100% PE treatment each year (Table 5).

Table 5. Analysis of variance and mean comparison for seed quality tests and average values in 2006 and 2007 from different treatments.

Variation source	DF[a]	Conductivity		Seedling growth rate: Seedling length		Seedling growth rate: Seedling dry weight		Standard germination: Percentage		Standard germination: Rate		Cool-germination: Percentage	
		F Value	Pr>F	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F
Year	1	630.14	<0.0001	15.39	0.0078	12.91	0.0115	0.60	0.4736	133.55	<0.0001	15.45	0.0077
Treatment	3	9.38	0.0008	18.80	<0.0001	5.40	0.0093	3.31	0.0572	11.06	0.0002	1.10	0.3807
Treatment × Year	3	15.33	<0.0001	5.21	0.0106	1.89	0.1716	1.08	0.3945	5.19	0.0093	3.89	0.0306
		Conductivity ($\mu S\ cm^{-1}\ g^{-1}$)		Seedling length (cm)		Seedling dry weight ($mg\ d^{-1}$)		Percentage (%)		Rate (h^{-1})		Percentage (%)	
Irrigation regimes (% PE[b])		2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
100		30	36	15	12	21	18	75	75	0.027	0.035	74	39
70		24	40	18	12	25	18	87	80	0.027	0.036	68	58
40		27	30	18	17	25	25	82	90	0.027	0.036	76	56
0		26	38	20	22	26	24	87	97	0.040	0.038	69	60
$LSD^{(0.05)}$		2.22	3.04	2.33	3.15	NS	4.91	NS	11.12	0.00568	NS	NS	15.32

[a] DF: Degree of freedom.

[b] PE: Class A pan evaporation.

Germination rate was not significantly affected by irrigation regimes in 2007, but it was significantly affected by irrigation regimes in 2006. However, there were generally no significant differences between 40, 70 and 100% PE, but germination rate were significantly increased in 0% PE regime (Table 5).

In both years, there was a significant effect of irrigation regimes on conductivity (Table 5). The conductivity test indicated that 100% PE treatment had the lowest seed vigor in 2006. The conductivity also was not significantly different in irrigation regime between 0, 40 and 100% PE, but was significantly decreased with 70% PE treatment in 2007.

One of the more important results of irrigation regimes is the effect on seedling length and dry weight (Table 5). Seedling length decreased with increasing irrigation levels and differed significantly among irrigation regimes each year. Seedling length was highest in 0 and 40% PE regimes each year, and there was no significant difference among these regimes. The largest seedling lengths were obtained from the 0 and 40% PE and the smallest seedling length were observed from the 100% PE treatment. The average values for actual seedling length (Table 5) indicated that maximum seedling length was achieved from 0 until 40% irrigation levels. Seedling dry weight also decreased with increasing irrigation levels with no significant difference among irrigation regimes in 2006, but significant differences among irrigation regimes in 2007 (Table 5). The results of seedling dry weight were similar to the results of seedling length.

There was no significant difference among irrigation regimes for cool germination in 2006, but a significant difference among irrigation regimes in 2007. In general, the germination percentage in cool germination tests decreased with increasing irrigation levels in 2007. Overall, germination percentage was highest with 0% PE treatment in the cool germination test. The average values for actual cool germination (Table 5) indicated that maximum germination percentage was achieved from 0 until 70% PE irrigation levels.

Discussion

Lint yields showed quadratic responses to %PE, increasing, reaching a maximum at 82-91% PE, and then decreasing with increasing %PE. Karam. et al. (2006) reported that cotton lint yield reduced as irrigation amounts increased in cotton. They found that the highest cotton lint yield was obtained from total irrigation of 549 mm (639 kg ha^{-1}) and the smallest yield was observed from total irrigation of 633 and 692 mm (577 and 547 kg ha^{-1}), respectively. Detar (2008) reported that optimum water application regime for cotton yield was 95% of pan evaporation and that reducing the application rate by 5% below the optimum level would decrease the yield by 4.6%. Doorenbos and Kassam (1979) indicated that the maximum cotton yield was usually obtained when the cotton plants were irrigated at 50-60% of available water holding capacity. Bang and Milroy (2000) stated that cotton plants under full irrigation experienced increased vegetative growth, delayed maturity, and reduced number of open boll; the result can be a reduction in yield. On the contrary, Dagdelen et al. (2009) and Ibragimov et al. (2007) reported that the largest average cotton yield was obtained from the full irrigation regime in cotton. Singh et al. (2010) reported that further increase in deficit irrigation from 0.7 Etc to 0.5 Etc significantly decreased seed cotton yield over its subsequent higher irrigation levels. Ertek and Kanber (2001) studied the effects of different drip irrigation regimes on DM yield of cotton and stated that the largest DM yield was 0.71 kg m^{-2} under their well-irrigated treatment in Cukurova Plain, located in southern Turkey. Cotton yield depends on the production and retention of bolls, and both can be decreased by water stress (Yazar et al., 2002).

Seed weight increased with increasing %PE each year, up to a maximum at 63-100% PE. Shock et al. (2007) reported that seed weight of alfalfa increased with increasing water levels. By contrast, Iannucci et al. (2002) found that 1000-seed weight of alfalfa increased in the absence of irrigation. Brown et al. (1977) also reported that irrigation treatment had only a slight effect on seed weight. Bannayan et al. (2008) reported that the lowest seed yield of black cumin was obtained when irrigation was stopped at the blooming stage, but thousand seed weight was relatively stable across all irrigation treatments.

Germination and vigor of seeds generally increased with increasing deficit irrigation each year. Shock et al. (2007) in alfalfa also reported that germination decreased with increasing water levels. In contrast, Heatherly (1993) reported that irrigation initiated during flowering and continued into the seed-fill period significantly increased standard germination of soybean seed. Vieira et al. (1992) also found that water stress increased seed conductivity in soybean cultivars. Ghassemi-Golezani et al. (1997) on maize and sorghum and Vieira et al. (1992) on soybean and Iannucci et al. (2002) on alfalfa reported that although water limitation in whole growing season could reduce yield, it had no significant effect on their seed germination.

Furthermore, the data showed that limited water resulted in reduced seed yield, but there were no adverse effects on seed germination and vigor. In fact, seeds from deficit irrigation showed higher germination and vigor levels with seed vigor tests (standard germination, seedling growth rate and cool germination tests).

Conclusions

In this study, our results demonstrated that the amount of irrigated water has a significant effect on lint yield and seed quality of cotton and highlighted some clear guidelines for producing the lint yield and seed. Here it was shown when the amount of applied water was reduced to 30 (70% PE) and 60% (40% PE), lint yield decreased by about 4 and 14%, respectively, and the highest seed quality accompanied by lint yield were observed with irrigation treatments of 40 and 70% PE. Therefore, in areas where water shortage prevails (Mediterranean regions), deficit irrigation under drip system appears to have a great potential for saving large quantities of water, which will help in bringing more areas under irrigation, resulting in a large increase in productivity and also seeds of higher quality.

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