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Original Article

Cotton Response to Planting Patterns under Effect of Typical and Limited Irrigation Regime

Mohammed K. DARAWSHEH[1*], Ioanna KAKABOUKI[2], Ioannis ROUSSIS[2], Dimitrios J. BILALIS[2]

*[1]Hellenic Agricultural Organization-Demeter/Institute of Industrial & Forage Crops - National Cotton Classification Centre, 1st km Karditsa-Mitropili, 43100 Karditsa, Greece; ethiage@otenet.gr (*corresponding author)*

[2]Agricultural University of Athens, Department of Crop Science, Laboratory of Agronomy, 75 Iera Odos Str., 11855 Athens, Greece; i.kakabouki@gmail.com; iroussis01@gmail.com; bilalisdimitrios@gmail.com

Abstract

Decrease of width between cotton (*Gossypium hirsutum* L.) row spacing has been suggested as an agronomic practice that may increase the yield and reduce the cost production. Altering agronomic practices as row spacing system as well as irrigation regime can affect cotton growth parameters, yield components, and physical fiber properties. The object of this study is the assessment of interaction between row spacing cropping systems and irrigation regime and their effects on yield components. Yield, biomass, harvest index, seed index, seed weight, bolls number, individual boll weight, the proportion of lint and seed were studied in three row spacing systems [conventional row (CR), narrow row (NR) and ultra-narrow row (UNR)] under typical and limited irrigation regime, during two growing seasons. The decrease of row spacing had different effect on yield components under the typical and limited irrigation regime e.g. the differences between systems of row spacing on bolls number were more evident under the limited irrigation than the typical one, and the opposite was true for the lint proportion. Decreased row spacing had positive effects on yield, biomass, bolls number per land area and lint proportion in two irrigation systems. However, had negative impact on individual boll weight, seed weight, seed index, harvest index and seed proportion. Interaction of row spacing and irrigation regime was significant for seed index. High differences were more significant between UNR and CR and less between NR and CR. UNR system appeared to be viable alternative to traditional row system for cotton production.

Keywords: cotton; harvest index; irrigation regime; planting pattern

Introduction

Cotton is the world's primary fiber crop and is a major agricultural commodity in over 30 countries. However lately, cotton growers are faced with the difficult task of selecting management strategies under rising production costs and declining returns for their crop. To deal with high rise of cotton production cost, growers have adopted management practices such as decreased row spacing, to maximize crop profit.

Commonly, cotton is planted in conventional row spacing (CR) ranged about 96 to 100 cm. In the last few years narrow (NR) and ultra-narrow row (UNR) was investigated as alternative cropping system. Altering row spacing can affects growth parameters, yield components as well as quality cotton parameters (Darawsheh, 2010). The decrease of cotton row spacing can increase the light's capture early in season, by producing a larger canopy or LAI (Darawsheh *et al*., 2009b), that provides more assimilate for reproductive growth and can result in higher yields (Heitholt *et al*., 1992). Decreased cotton row spacing may increase the yield (Gerik *et al*., 1998; Nichols *et al*., 2004), and reduce the weed competition (Snipes 1996). It can also reduce soil water evaporation (Howell *et al*., 1984), due to additional shading of the soil (Enciso-Medina *et al*., 2002), because of rapid canopy closure (Jost and Cothren, 2000). Lascano and Nelson (2014) have suggested decreased row spacing system as an agronomic practice that can maximize cotton's water use efficiency.

Effect of planting pattern (row spacing) on cotton growth and yield were studied by several researches (Jost and Cothren, 2001; Valco *et al*., 2001; Nichols *et al*., 2004; Darawsheh *et al*., 2007; Darawsheh *et al*., 2009b; Stephenson *et al*., 2011); however, these studies

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documented only the effect of planting pattern on crop without reference of the impact of irrigation regime.

The perennial, indeterminate growth habit and the specific adaption of cotton to water regime (Hearn, 1994) make it extremely sensitive to environmental conditions and management practices (Oosterhuis, 1994). A specific adaption of cotton to water regime has a profound impact on crop performance and yield and fiber quality. Cotton production in most of the countries as in Greece is dependent upon irrigation to supply the majority of crop water demand. Most semi-arid areas of the world, as well as Greece, face the problem of limited water resources which prevents of full crop irrigation, especially during periods of low rainfall which are frequent at latest years.

Numerous studies (Gerik *et al*., 1996; Pettigrew, 2004; Mert, 2005; Warwick *et al*., 2005; Campbell and Bauer, 2007; Karademir *et al*., 2011; Park *et al*., 2012; Yagmur *et al*., 2014; Lascano *et al*., 2015) over the past years have addressed how cotton yield and yield components are altered under the effect of limited irrigation regime, though these studies investigated this hypothesis only in conventional row spacing system. However, little is known to our knowledge about combined effects of row spacing cropping systems and irrigation regime. Determining interaction of planting pattern and irrigation regime will assist growers and the consultants in developing efficient production and best management systems for cotton production.

This work addressed the hypothesis that irrigation regime could alter the effect of row spacing on cotton yield and yield components and focused on the assessment of interaction effects of decreased row spacing and irrigation regime on yield parameters. During two successive cotton growing seasons, yield, bolls number and weight, biomass production, harvest index, seed index and fiber proportion were studied under the effects of three cotton row spacing systems, NR, UNR and CR and two irrigation regimes, a typical and a limited one.

Materials and Methods

Consecutive field experiments were conducted during two growing seasons (2015-2016), in central Greece, Thessaly region - Palama - Karditsa (N 39°33'-39°03', E 21° 22'-22°15'). Cotton was seeded on a silt loam soil in three width row spacing systems, CR (96 cm), NR (75 cm) and UNR (50 cm). Plant population density per land area was 12-14 m^{-2} for CR, 13-15 m^{-2} for NR, and 15-16 m^{-2} for UNR. Typical plant population in conventional row spacing (96 cm) in this region is about 12-16 plants per m^2. Sowing took place on 12 April in both years.

Two irrigation regimes were applied: a typical one based on field capacity and rainfall events during the growing season which was defined as typical, and one half of typical irrigation which was defined as limited irrigation. The typical irrigation regime was scheduled as defined for this region by Cotton Board for sustainable production by a drip irrigation system. The applied water quantity for each irrigation regime during two years and application calendar are presented in Table 1. The same irrigation program was applied for limited irrigation, but with one half of water quantity for each irrigation.

All the other cultivation practices were those applied by the growers in the certain region, namely pre-planting fertilization 400 kg ha^{-1} (20-10-0), and post planting application at the stage of square emergence of 100 kg ha^{-1} potassium nitrate. Weed control practices included pre-plant incorporated Treflan® (trifluralin) and hand-weeding treatments to maintain weed-free plots were also applied. The commercial cultivar, Acalla type, exhibiting moderate early maturing and medium sympodial branches was evaluated under the applied treatments.

The experimental design was a randomized complete block with split-plot, where irrigation treatments (typical and limited regime) were the main plots and the row spacing treatments the subplots. Between the main plots of irrigation there was a buffer zone of 3 m. Four replications of the same practice in each experimental plot were followed in both years. Each plot was 30 m long, consisted of 6 rows (6 m width) in CR treatment, 12 rows (6 m width) in UNR and 8 rows (6 m width) in NR row spacing system.

In order to estimate the seed cotton production, bolls were harvested by hand for each treatment. The biomass was estimated by the vegetative upper plants parts that remained in the field after bolls harvest. Individual boll weight, lint and seed percentage were estimated from the harvested bolls. A laboratory gin machine, saw ginning system, was used to separate the fiber and seed. For the estimation of biomass moisture three samples per treatment were oven dried at 85 °C for 48 hours. Seed-cotton moisture was measured by Mahlo DMB-10 cotton moisture meter. The determination of moisture was used for the estimation of harvest index (weight of biomass/weight of seed-cotton) under the same moisture of seed-cotton and biomass.

All data were subjected to ANOVA analysis. Repeated measure ANOVA was used to analyze the data across years, and in order to estimate the effect of year and the interactions of year× row spacing and year × irrigation. All data analyzed at P 0.05. To estimate the significance between means, Fisher's protected least significant difference (LSD) test was used. Also, LSD test for means was analyzed apart for each irrigation regime

Results

Seed-cotton yield

The effects of limited irrigation on seed-cotton yield were evident in both years and in all row spacing systems (Fig. 1). Under limited irrigation, seed-cotton reduction in all spacing treatments was about 40%. The observed seed-cotton production when limited irrigation was applied was significantly higher in decreased row spacing system (UNR-50 cm) compared to the other cultivation systems. In contrast, typical irrigation regime in both years had minor effects on the mean seed cotton yield regarding row spacing, and according to LSD test (Table 3) significant differences were observed only between UNR and CR treatments. No significant interaction effect was recorded between row spacing and irrigation, neither between year and row spacing or between year and irrigation were not significant (Table 4). Cotton seed yield was also significantly affected by year ($P < 0.001$).

Table 1. Irrigation water quantity (mm) and application date during two years (2015 and 2016) for normal and typical irrigation regime

Date	Typical irrigation mm		Limited irrigation mm	
	1st year	2nd year	1st year	2nd year
5 May	-	20	-	10
12 May	20	-	10	-
15 May	-	20	-	10
5 June	-	30	-	15
15 June	30	30	15	15
25 June	30	30	15	15
7 July	40	40	20	20
21 July	50	50	25	25
31 July	60	50	20	20
15 August	60	-	30	-
18 August	-	50	-	25
27 August	60	-	30	-
28 August	-	50	-	25
15 September	40	40	20	25
SUM	**390**	**410**	**185**	**205**

Table 2. Means of meteorological data during two growing seasons

Months	Mean Temp. °C		Precipitation mm		R. humidity %		Degree days***	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
April*	13.7	15.0	17.6	52.8	74.7	70.7	0.0	6.3
May	19.8	20.1	61.2	4.8	67.0	56.0	136.8	130.3
June	24.7	25.0	42.0	5.6	58.2	52.3	266.5	278.3
July	28.2	26.4	0.0	2.6	57.9	52.9	375.1	320.1
August	27.2	26.0	12.4	20.4	42.3	53.1	347.1	314.8
September**	21.4	20.5	27.6	25.2	52.8	68.6	171.7	160.9

*After 15 April, **until 15 Sep., ***Degree days based on 15.5 °C

Table 3. LSD test, significance differences between means (average of two years) of seed-cotton, biomass, and yield components in Ultra narrow row (UNR), Narrow row (NR) and Conventional row (CR) systems under limited and typical irrigation regime

Growth Parameters	Limited Irrigation				Typical Irrigation			
	Row Spacing	Row Spacing			Row Spacing	Row Spacing		
		UNR	NR	CR		UNR	NR	CR
Seed Cotton Yield	UNR		*	***	UNR		NS	*
	NR	*		NS	NR	NS		NS
	CR	***	NS		CR	*	NS	
Biomass Yield	UNR		**	***	UNR		**	***
	NR	**		**	NR	**		*
	CR	***	**		CR	***	*	
Harvest Index	UNR		NS	**	UNR		NS	*
	NR	NS		*	NR	NS		NS
	CR	**	*		CR	*	NS	
Bolls Number	UNR		**	***	UNR		NS	***
	NR	**		***	NR	NS		*
	CR	***	***		CR	***	*	
Boll Weight	UNR		NS	***	UNR		NS	***
	NR	NS		***	NR	NS		**
	CR	***	***		CR	***	**	
Seed Index	UNR		NS	NS	UNR		***	***
	NR	NS		*	NR	***		NS
	CR	NS	*		CR	***	NS	
Lint %	UNR		NS	***	UNR		**	***
	NR	NS		**	NR	**		***
	CR	***	**		CR	***	***	
Seed %	UNR		NS	***	UNR		**	***
	NR	NS		**	NR	**		***
	CR	***	**		CR	***	***	

NS: not significant. Y: year. IRR: irrigation. RS: row spacing. * $P \leq 0.05$, ** $P \leq 0.01$ and *** $P \leq 0.001$.

Table 4. Interaction of row spacing and irrigation on seed-cotton yield, biomass production and yield components, and repeated measures analysis of variance for means of two years.

Source	Cotton Yield	Biomass Production	Harvest Index	Bolls Number	Boll weight	Seed Index	Lint %	Seed %
Irrigation (IRR)	***	***	*	***	***	**	***	**
Row spacing (RS)	**	***	***	***	***	***	***	***
RS × IRR	NS	NS	NS	NS	NS	NS	**	NS
Year (Y)	***	***	*	***	***	NS	***	*
Y × IRR	NS	**	NS	***	***	NS	**	NS
Y × RS	NS	**	*	Ns	*	***	**	***
Y×RS×IRR	NS	NS	NS	**	NS	NS	NS	NS

NS: not significant. Y: year. IRR: irrigation. RS: row spacing. *$P \leq 0.05$. **$P \leq 0.01$, and ***$P \leq 0.001$.

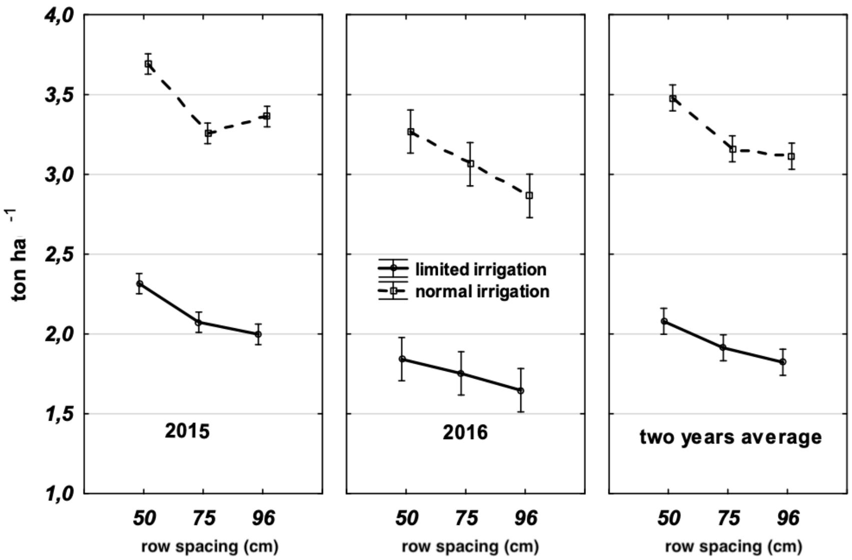

Fig. 1. Seed cotton production within years and average across two years under the interaction of row spacing and irrigation regime (limited and typical or normal). Vertical bars represent ± standard error

Biomass production

Biomass (Fig. 2) was also affected by the applied irrigation regime. The recorded biomass was impressively higher in UNR compared to CR and NR cultivation systems under both irrigation regimes, with most prominent results under limited irrigation. Thus, under limited irrigation the recorded biomass was about 32.7% and 15% (data not showed) higher in UNR compared to CR and NR respectively. However, under typical irrigation it was about 27.8% and 16.6% (data not showed) higher in UNR than in CR and NR respectively. Also, the limited irrigation regime comparatively with the typical one decreased the biomass about 39%-41% in all row spacing systems. According to repeated analysis of variance (Table 4), year showed high effect on biomass and the interaction effects between year × row spacing and year × irrigation, were high significant ($P < 0.001$).

Harvest Index (HI)

Harvest index (Fig. 3) was significantly lower in UNR and NR compared to CR cultivation system when limited irrigation regime was applied (e.g. the harvest index was about 13% lower in UNR than in CR, and about 8% lower in NR than in CR). Additionally, harvest index was reduced by 5-6% in limited irrigation compared to typical irrigation regime. Harvest index seemed to be affected more by row spacing than by the applied irrigation system. Interaction effects between row spacing and irrigation regime were not significant on harvest index as well as between year and irrigation, but was between year and row spacing.

Bolls number and individual boll weight

Bolls number m^{-2} (Fig. 4) was significantly ($P < 0.001$) higher in UNR treatment, compared to cotton planted in NR and CR. The observed differences were more evident under the limited irrigation regime than the typical one. For example, the bolls numbers in UNR system, under limited irrigation were about 29% and 10.3% higher than in CR and NR respectively, while under typical irrigation the respective rates were 23% and 9%.

In contrast to the bolls number, boll individual weight (Fig. 5) was significantly greater in CR treatment than in cotton planted in UNR and NR under both irrigation systems. Limited irrigation regime compared to typical one decreased the bolls number by 27%, 28% and 30% in UNR, NR and CR respectively, while the respective decrease for boll weight was about 20%, 18% and -14%, respectively.

Row spacing and irrigation regime interaction effects were not significant on both bolls number and individual boll weight. However, year as well as interaction effect of year and irrigation were significant ($P < 0.001$) on bolls number and weight.

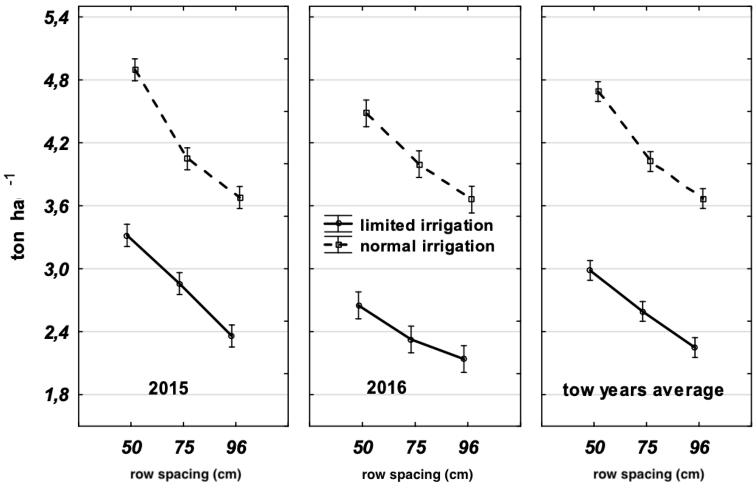

Fig. 2. Biomass cotton production within years and average across two years under the interaction of row spacing and irrigation regime. Vertical bars represent ± standard error

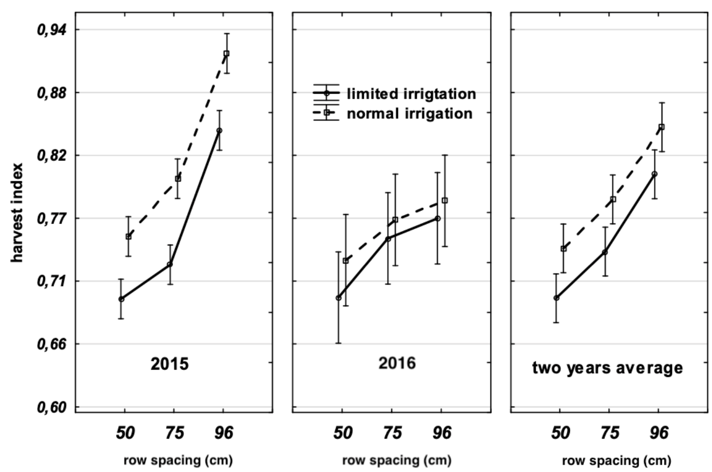

Fig. 3. Harvest index within years and average across two years under the interaction of row spacing and irrigation regime (limited and typical or normal). Vertical bars represent ± standard error

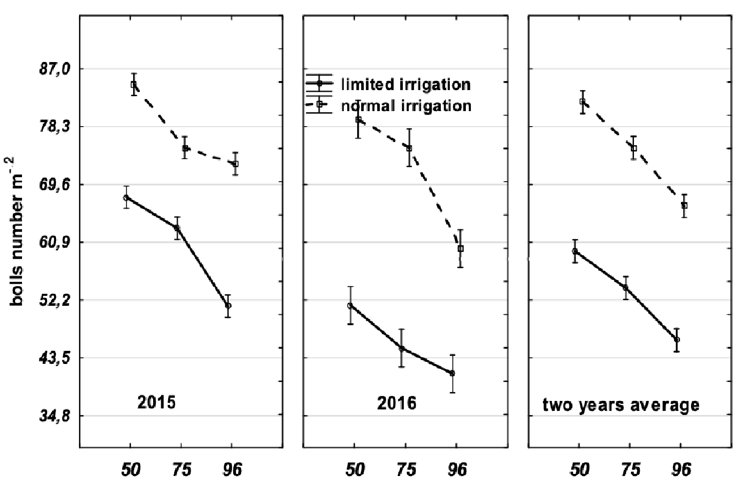

Fig. 4. Bolls number within years and average across two years under the interaction of row spacing and irrigation regime (limited and typical or normal). Vertical bars represent ± standard error

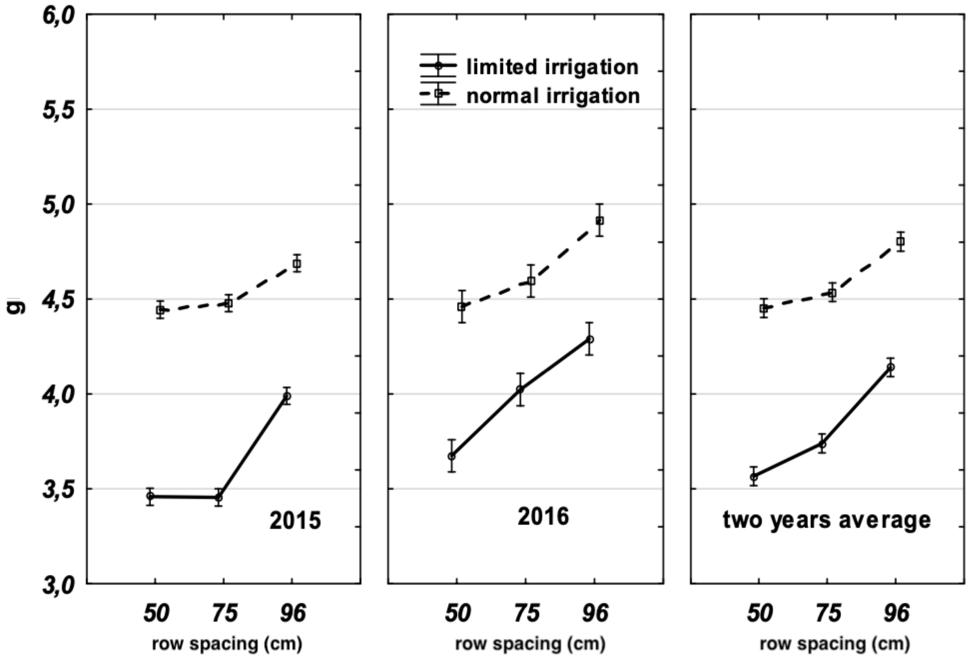

Fig. 5. Individual boll weight within years and average across two years under the interaction of row spacing and irrigation regime. Vertical bars represent ± standard error

Seed Index (Weight of 100 seeds)

Seed index in contrast to other parameters was negatively affected by both decreased row spacing and as well as irrigation regime. The recorded seed index (Fig. 6) was reduced by 3.7% and 2.0% in UNR compared to CR and NR when limited irrigation was applied. Under typical irrigation treatment, the calculated seed index was 8.8% and 7.1% lower in UNR than in CR and NR respectively. When limited irrigation was applied a reduction of seed index was observed by 20%, 19% and 14% in UNR, NR and CR respectively. In contrast to the other parameters significant interactions of row spacing and irrigation, also by year and row spacing as well as by year and row spacing (Table 4) were recorded on seed index. LSD test (Table 3) showed that row spacing effect on seed index was more significant under typical irrigation than under the limited one.

Lint and seed proportion (%)

The lint proportion (Fig. 7), in contrast to seed proportion, was affected positively by decreased row spacing and limited irrigation regime, thus the highest lint proportion was observed (P < 0.001) in UNR and under limited irrigation. Differences on lint proportion among the three spacing were more significant under typical irrigation and less in limited one (e.g. differences on lint proportion between UNR and NR were significant (P >0.01) only under typical irrigation and were not (P < 0.05) under limited one). Lint proportion in three row spacings (UNR, NR and CR) was also higher by 1.2 %, 1.45% and 1.3% in limited irrigation than in typical one in UNR, NR and CR respectively. As is expected the adverse results were observed for the seed proportion (Fig. 8), namely seed proportion was lower in UNR than in CR and NR and was lower in limited irrigation than in typical one in three row spacing treatments. Seed and lint proportion were significantly affected by the row spacing and the irrigation regime, but not by interaction effects between row spacing and irrigation regime. Significant interaction effects were observed only between the year and the row spacing treatments.

Discussion

Row spacing decrease, especially from 96 cm (CR) to 50 cm (UNR), positively affected both seed-cotton and biomass production having more prominent results to the prominent to the biomass. This fact led to higher harvest index in UNR, compared to CR treatment. According to previous research (Kerby *et al.*, 1990; Darawsheh *et al.*, 2009b), due to higher plant density in UNR, a greater proportion of photoassimilates is probably directed to vegetative (V) growth rather than to reproductive (R) growth, leading in greater V/R ratio.

Despite of interaction lack between row spacing systems and irrigation regimes on yield, the positive impact of decreased row spacing on yield were more pronounced (LSD test) in limited irrigation regime than in typical one. According to Enciso-Medina *et al.* (2002) the water use efficiency in UNR was higher than either the 76 cm or 102 cm row spacing system, also soil water evaporation can be reduced due to the additional shading of the soil by decreasing the spacing between rows to about 25 to 50 cm. These findings of previous researchers could be associated with the higher yield in UNR compared to CR under limited irrigation compared to typical one in this study. The

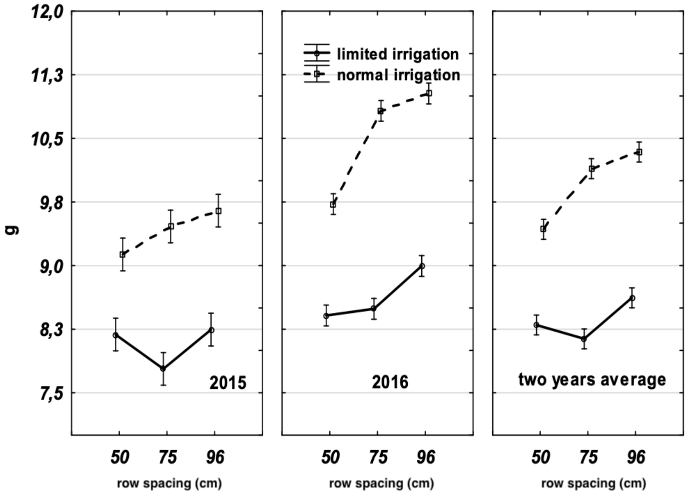

Fig. 6. Seed index within years and average across two years under the interaction of row spacing and irrigation regime (limited and typical or normal). Vertical bars represent ± standard error

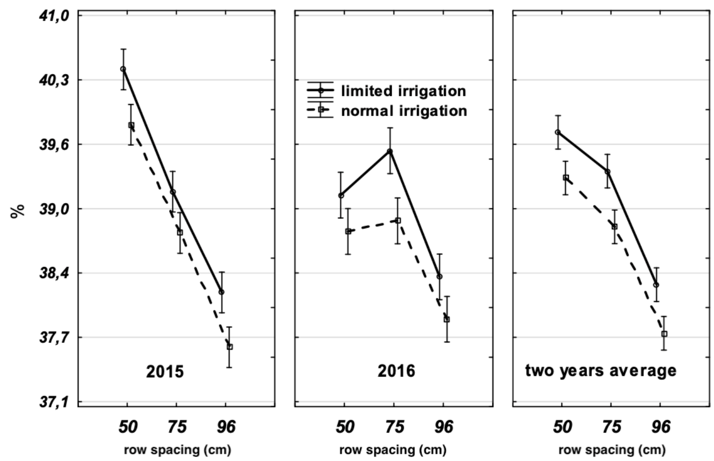

Fig. 7. Lint proportion within years and average across two years under the interaction of row spacing and irrigation regime (limited and typical or normal). Vertical bars represent ± standard error

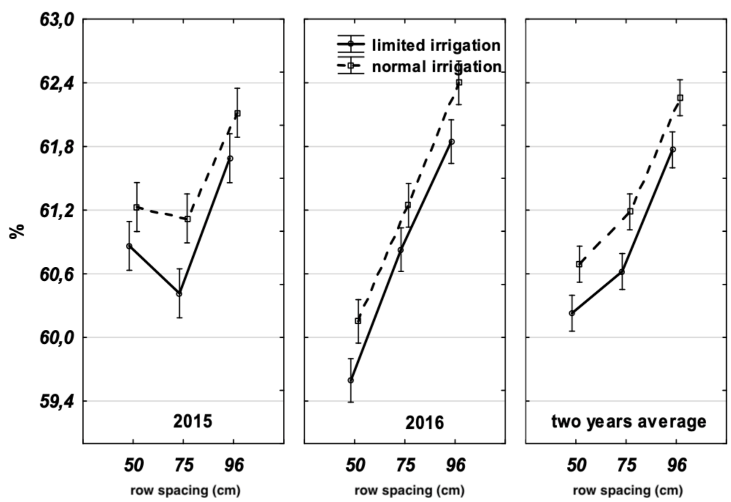

Fig 8. Seed proportion within years and average across two years under interaction of row spacing and irrigation regime (limited and typical or normal). Vertical bars represent ± standard error

recorded higher lint yield in UNR is in accordance to Reddy *et al.* (2009) that reported 38% higher lint yield in UNR compared to CR in non-irrigated cotton, while these differences between two systems were less in irrigated cotton (24%). In this study, cotton in UNR in comparison with cotton in CR produced 14% and 11% higher yield under limited and typical irrigation regime respectively. On the other hand the higher cotton yield in UNR may be also associated with the rapid canopy closure as this was reported by previous researches (Jost and Cothren, 2000; Reddy *et al.*, 2009) and high LAI (Darawsheh *et al.*, 2009b) which permits light interception early in the season (Heitholt *et al.*, 1992) when leaf area index has not reached yet its optimum.

Bolls number per land area in the present study was significantly higher ($P \leq 0.001$) in UNR, compared to NR and CR row spacing systems and this was more evident under limited irrigation compared to typical one as this was reported on yield data. Thus, the higher yield in UNR, compared to CR was due to higher bolls number per land area (m^2) in UNR and not due to bolls number per plant as this was recorded by a previous research (Reddy *et al.*, 2009), because in this study bolls number plant^{-1} were lower in UNR than in CR (data not showed). Limited irrigation regime strongly reduced the bolls number in all row spacing systems by 27%-30%. Similar results were recorded by Mert (2005) and Yagmur *et al.* (2014) in non-irrigated cotton stands.

In contrast to bolls number, individual boll weight was negatively affected ($P \leq 0.001$) by decreased row spacing under both irrigation regimes e.g. boll weight was less by 14% and 7.3% in UNR than in CR under limited and typical irrigation respectively. In addition, the applied limited irrigation regime strongly reduced the boll weight, in all cultivation systems. The negative effect of irrigation deficit on boll weight was also reported in previous literature (Gerik *et al.*, 1996; Coker *et al.*, 2009; Onder *et al.*, 2009; Yagmur *et al.*, 2014); however, according to Pettigrew (2004), it was not the soil moisture that influenced the boll weight.

Seed index was affected negatively ($P \leq 0.001$) by decreased row spacing as well as by the applied limited irrigation. Also, seed index was the only parameter that was significantly ($P \leq 0.01$) affected by interaction between row spacing and irrigation. According to LSD test, seed index was affected more by row spacing under typical irrigation than under limited regime. Negative effect of limited irrigation or non-irrigated cotton on seed weight was also found by other studies (Mert, 2004; Pettigrew, 2004). According to previous researches (Darawsheh *et al.*, 2007 and 2009a) seed index was lower under a high plant population density, namely in UNR than in CR.

The lint proportion was affected positively by both decreased row spacing and limited irrigation regime, while the opposite effect was recorded for the seed proportion. The results are in agreement with Onder *et al.* (2009) and Yagmur *et al.* (2014), whilst otherwise is reported by Karademir *et al.* (2011) and Campbell and Bauer (2007). On the other hand, Pettigrew (2004) reported that lint percentage response to irrigation varied depending on the genotype. Higher lint percentage in UNR than in CR was also found by Bednarz *et al.* (2005) and Reddy *et al.* (2009) recorded higher lint percentage in UNR than in CR only in the irrigated cotton, but not in non-irrigated. In this study the lint percentage was higher in UNR than in CR in both irrigation regimes. The higher lint proportion (or the lower seed proportion) under limited irrigation especially in decreased row spacing may be explained by the negative effects of both limited irrigation and decreased row spacing on seed index and individual boll weight. Thus, limited irrigation and decreased row spacing may not increase lint proportion, but the result might be attributed to the high decrease of seed weight.

The response of seed weight and seed percentage to row spacing and irrigation regime seemed to be a complex relation. These results in combination with the significant row spacing × irrigation interaction indicated that, irrigation can alter the effect of row spacing on seed-cotton and biomass production. Thus, effects of row spacing × irrigation, year × row spacing, and year × irrigation interactions on seed weight were highly significant.

Conclusions

The decreased row spacing e.g. from 96 (CR) to 50 cm (UNR) may be a potential alternative agronomic practice that can increase the yield under typical and limited irrigation regime, when the used plant population per land area in UNR and CR was about the same. Despite of interaction lack between row spacing and irrigation regime on most yield components, separate LSD test for each irrigation, indicated that effects of row spacing system on yield components may be altered under different irrigation regime as this of typical and limited irrigation regime which were used in this study. High significant interaction between row spacing and irrigation was presented on seed index.

Conflict of Interest

The authors declare that there are no conflicts of interest related to this article.

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