Irrigation-Water and Cotton

Subjects: Agricultural Engineering
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A decrease in water resources, as well as changing environmental conditions, calls for efficient irrigation-water management in cotton-production systems. Cotton (Gossypium sp.) is an important cash crop in many countries, and it is used more than any other fiber in the world.

Keywords: cotton ; water management ; yield ; water productivity

1. Introduction

The global production of cotton fiber is estimated to be 24.65 million tons [1]. In 2018, the production was estimated to be 6.71 million tons in the Americas; 0.38 million tons in Europe; 1.56 million tons in Africa; 0.95 million tons in Oceania; and 15.06 million tons in Asia [1]. In 2020, across the United States, the production of cotton was estimated to be 3.26 million tons, and cotton was grown on about 3.52 million hectares [2]. The United States is the world's leading cotton exporter, supplying about 35% of global cotton exports in recent years [3]. Cotton is a valuable, natural-textile fiber and the purest source of cellulose [4]. Aside from the fibers, cotton also is produced as a source of seeds that provide edible oil, seed by-products, and other products to industries. Its residues provide organic matter to the soil. Zhang and Dong [5] estimated that cotton fiber contributes to half of the world's clothes.

Therefore, improved irrigation-water management practices that optimize the lint and seed yield of cotton and promote water-use efficiency, while maintaining maximum quality, are critical for the future sustainability of cotton production.

2. Cotton Water-Use Efficiency

The concept of water-use efficiency (WUE) was introduced more than 100 years ago by Briggs and Shantz [6] indicating a relationship between plant productivity and water use. Cotton lint yield is found to rise with increasing crop water use [7]. Hatfield and Dold [8] defined WUE as the quantity of assimilated carbon in terms of biomass or grain per unit of water used by the crop. In plant breeding, it has been proposed to use WUE to select water-use-efficient genotypes under changing environments, heat and water stress, and the interactions between them. Research results have revealed variations between genotypes for WUE in upland cotton and pima cotton [9][10][11]. Snowden et al. [12] carried out a study on WUE and irrigation response of cotton cultivars under subsurface drip irrigation in West Texas, USA. They reported that WUE differed among the six cultivars and the deficit strategies used. In 2010, the cotton variety FM9160 had the greatest WUE of 0.20 kg m^{-3} under severe deficit irrigation; DP1044 had the greatest WUE of 0.32 kg m^{-3} under mild deficit irrigation; and DP0912 had the greatest WUE of 0.33 kg m^{-3} under full irrigation (**Table 1**). Among the irrigation regimes, full irrigation provided the highest WUE while severe deficit gave the lowest WUE in 2010. Moreover, a study conducted in Australia found that the water-use efficiency increased by 40% over a ten-year period along with developments in plant breeding, the utilization of genetically modified varieties, and improved water management practices, and they resulted in yield increases [13]. These results are in line with the findings of Hatfield and Dold [8] who reported that WUE is dependent upon genotype and management practices. Evett et al. [14] reported that evapotranspiration water-use efficiency (ETWUE) ranged from 0.15 kg/m^3 to 0.33 kg/m^3. The improvement in ETWUE is most probably attributable to increased yield as well as to reduced soil evaporation and transpiration. It was deduced that management practices that lessen soil water evaporation and move the water for crop water use (more transpiration) reduce crop exposure to water stress and maintain water-use efficiency at the maximum level possible. For instance, Hatfield and Dold [8] reported that the adoption of drip irrigation reduced by 23% wheat water use, but, at the same time, it improved yield by 37%. In cotton, this practice reduced water use by 37% and diminished yield by 21%. Therefore, the use by farmers of micro-irrigation systems, such as drip-irrigation, lessens not only the soil water evaporation from between plant rows early in the season but also prevents almost all the evaporation component from the canopy. These management practices have a positive effect on WUE in areas where crops are micro-irrigated and show that WUE can be improved by water management practices.

Table 1. Irrigation regimes, yield, and water-use efficiency (WUE) (SE—severe deficit, MD—mild deficit, F.irr—full irrigation, DI—drip irrigation, SDI—subsurface drip irrigation, CEF—closed-end furrow).

Location	Year	Watering Regime	Yield (kg ha^{-1})		Water-Use Efficiency (kg m^{-3})			Cotton Variety	References
			Lint	Seed	WUE	IWUE	ETWUE		
West Texas, USA	2010	SE	712		0.20			FM9160	Snowden et al. [12]
		MD	1436		0.32			DP1044	
		F.irr	1743		0.33			DP0912	
	2011	SE	596		0.15			DP0935	
		MD	1268		0.23			DP1044	
		F.irr	1537		0.22			DP0935	
Texas, California and Uzbekistan		DI					0.15–0.33		Evett et al. [14]
Turkey	2016–2017	SDI		4082	0.83	0.84			Cetin and Kara, [15]
Arizona, USA	1988–1999	N/A [1]	1280–1420				0.127–0.138	upland cotton	Grismer [16]
			910–120				0.09–0.109	pima cotton	
California, USA	1988–1999	N/A	1110–1440				0.134–0.210	upland cotton	
			1170–1340				0.151–0.177	pima cotton	

Location	Year	Watering Regime	Yield (kg ha^{-1})		Water-Use Efficiency (kg m^{-3})			Cotton Variety	References
			Lint	Seed	WUE	IWUE	ETWUE		
Bushland, Texas, USA	2003	MESA 100%	1229		0.164	0.492		Paymaster2280 BG RR	Colaizzi et al. [17]
		MESA 75%	1001		0.142	0.491			
		MESA 50%	536		0.089	0.288			
		MESA 25%	213		0.045	0.024			
		LESA 100%	1208		0.160	0.482			
		LESA 75%	984		0.143	0.480			
		LESA 50%	575		0.098	0.321			
		LESA 25%	288		0.058	0.130			
		LEPA 100%	1153		0.158	0.456			
		LEPA 75%	1149		0.164	0.581			
		LEPA 50%	685		0.109	0.415			
		LEPA 25%	362		0.072	0.234			
		SDI 100%	1150		0.159	0.454			
		SDI 75%	1082		0.152	0.540			
		SDI 50%	844		0.135	0.549			
		SDI 25%	491		0.092	0.416			
Turkey	2013	CEF 100%		5640	0.64	0.81		Nazilli-84	Dagdelen et al. [18]
		CEF 70%		4460	0.63	0.91			
		CEF 50%		3720	0.64	1.06			
		CEF 30%		3210	0.71	1.52			
		CEF(0%		1820	0.67	-			
	2014	CEF 100%		5340	0.62	0.74			
		CEF 70%		3990	0.62	0.79			
		CEF 50%		3590	0.73	0.99			
		CEF 30%		2800	0.74	1.29			
		CEF 0%		1740	0.72	-			
Bornova-Izmir, Turkey	1992–1994	Furrow			0.38–0.46	0.48–0.65		N84	Anac et al. [19]
Australia		Drip			2.23				Hodgson et al. [20]
		Furrow			1.89				

Location	Year	Watering Regime	Yield (kg ha^{-1})		Water-Use Efficiency (kg m^{-3})			Cotton Variety	References
			Lint	Seed	WUE	IWUE	ETWUE		
Anatolia, Turkey	1991–1994	Drip			0.487			Sayar-314	Cetin and Bidgel [21]
		Furrow			0.387				
		Sprinkler			0.236				
Harran plain, Turkey		LEPA			0.55–0.67	0.58–0.77			Yazar et al. [22]
		Drip			0.50–0.74	0.60–0.81			
Cukurova, Turkey		Furrow			1.9–5.9	1.5–5.1			Kanber et al. [23]

[1] None available.

Similarly, Evett et al. [14] revealed in several experimental studies at different locations of Texas and California in USA that water productivity (lint/evapotranspiration) and lint yield were improved by adopting drip-irrigation systems instead of furrow irrigation. In the same line, Fan et al. [24] found from a metadata analysis the highest cotton evapotranspiration water-use efficiency of 0.88 kg/m^3, and this can be achieved by lessening by 5.5% the crop water use. Moreover, subsurface drip irrigation at the 40 cm depth induced maximum cotton irrigation water productivity (WPirr) of 0.84 kg m^{-3}. Increasing the irrigation amount decreased the WPirr [15].

In recent years, the water-use efficiencies of cotton have been studied by many researchers to obtain optimum cotton yield by using less water. For example, Grismer [16] conducted a study on crop water productivity (CWP) for irrigated cotton in Arizona and California, USA. He found that, in Arizona counties, upland cotton actual evapotranspiration (ETc) water-use efficiency varied from 1.27 to 1.38 kg/ha-mm while, for pima cotton, it varied from 0.9 to 1.09 kg/ha-mm. In California counties, ETc water-use efficiency varied from 1.34 to 2.10 kg/ha-mm and 1.51–1.77 kg/ha-mm for upland and pima varieties, respectively. In western Turkey, Dagdelen et al. [18] reported WUE values varied from 1.59 to 2.30 kg m^{-3} for corn and from 0.61 to 0.72 kg m^{-3} for cotton in two years. WUE values of 0.38–0.46 kg m^{-3} were obtained by Anac et al. [19] in the coastal part of the Aegean region, Turkey.

It is important to highlight that WUE varies also according to the irrigation technology used. Some irrigation devices are found to limit water to the root zone, while others provide water to all the soil surface. Hodgson et al. [20] compared furrow and drip-irrigation methods for cotton and found that the WUEs were 2.23 and 1.89 kg m^{-3} for drip and furrow irrigation methods, respectively. Under drip, furrow, and sprinkler irrigation, Cetin and Bidgel [21] found water-use efficiencies of 4.87, 3.87, and 2.36 kg/ha-mm, respectively, proving that drip irrigation provides a greater yield per unit drop. Yazar et al. [22] reported that WUE values of cotton irrigated by LEPA and the drip method were, respectively, 0.55–0.67 kg m^{-3} and 0.50–0.74 kg m^{-3} in the Harran Plain in Turkey. Moreover, Kanber et al. [23] determined WUE values of 1.9–5.9 kg ha^{-1} mm^{-1} under furrow irrigation in the Cukurova Plain in southern Turkey and found irrigation water-use efficiency (IWUE) values for furrow irrigated cotton ranged from 1.5 to 5.1 kg m^{-3}. According to Anac et al. [19], IWUE values were 0.48–0.65 kg m^{-3}. In addition, IWUE values for LEPA and drip-irrigated cotton were 0.58–0.77 kg m^{-3} and 0.60–0.81 kg m^{-3}, respectively, in the Harran Plain of Turkey [22]. Ertek and Kanber [25] determined IWUE values for drip-irrigated cotton of 0.75–0.94 kg m^{-3} in the Cukurova Plain in Turkey. In Queensland, Australia, furrow irrigation has been optimized and tested in the field for cotton. Results showed an increase in WUE and a decline in labor requirement [26]. The water-use efficiency fluctuates between farming fields and across regions due to many factors. Therefore, site-specific measurements are crucial for decision making and improvements in WUE.

3. Cotton Yield and Yield Components under Different Irrigation Techniques

Cotton can be cultivated under rainfed conditions only in a limited number of regions, and usually an optimum yield cannot be achieved without irrigation [21]. Therefore, irrigation is necessary for cotton production. For instance, in the Mississippi Delta region, USA, Pinnamaneni et al. [27] reported that irrigation is a crucial factor in achieving both high fiber yield and seed quality, while Sui et al. [28] found out that irrigation augmented cotton yield and improved fiber length. Different irrigation technologies are widely used to produce cotton, with most common being:

- low-energy precision application (LEPA),
- low-elevation spray application (LESA),
- mid-elevation spray application (MESA),
- mobile drip irrigation (MDI),
- surface irrigation (SI),
- subsurface drip irrigation (SDI), and
- furrow irrigation (FI).

Various results have been obtained under different irrigation practices depending on local climates, soil conditions, genotypes, and management practices. In northern Texas and southwestern Kansas, USA, Colaizzi et al. [17] carried out a study in 2003 on cotton production with surface drip irrigation (SDI), LEPA, and spray irrigation, and found that the highest lint yield and water-use efficiency were achieved with SDI at low irrigation rates. Similar results were found by Colaizzi et al. [29] and Segarra et al. [30], who reported that SDI performed better than any other spray irrigation system (MESA, LESA, and LEPA). Moreover, the same study in 2004 revealed that lint yield and gross returns were improved with SDI at any irrigation rate. Bordovsky [31] found that under irrigation treatments with less than 50% of full irrigation, LEPA induced a 16% yield increase over sprinkler irrigation, but SDI resulted in a 14% higher yield over LEPA. At irrigation levels greater than 50% of full irrigation, yield was slightly smaller in sprinkler compared to LEPA, and SDI was found to provide a 7% greater yield than LEPA. However, Bordovsky et al. [32] carried out a study where soil matric potential was used to schedule irrigation and found that LEPA and drip irrigation provided the same yields for cotton, corn, and soybeans.

In Turkey, Cetin and Bidgel [21] carried out a study with three different irrigation methods on seed cotton yield and yield components and reported that maximum seed yield was 4380, 3630, and 3380 kg/ha under drip, furrow, and sprinkler irrigation, respectively. Drip irrigation generated 21% more yield than furrow irrigation and 30% more yield than sprinkler irrigation. In southeastern Turkey, Cetin et al. [33] did a similar study and compared different irrigation methods for effective water use on cotton. The highest seed cotton yield was found in drip-irrigated plots, and it was 4650 kg ha^{-1}. It was followed by furrow irrigation, which had a yield of 3120 kg ha^{-1}. In terms of lint yield, lint quality, and water-use efficiency, SDI has been found to slightly surpass LEPA and spray irrigation [30][34]. In India, Choudhary et al. [35] found that drip irrigation increased plant height, number of bolls per plant, boll weight, and number of monopods and sympods per plant. Further, water-use efficiency was greatest under drip irrigation as compared to other irrigation systems in all four cotton cultivars that Choudhary et al. [35] studied. According to Sezan et al. [36], for cotton production drip irrigation was more advantageous compared to conventional practices of irrigation. In China, Wang et al. [37] compared traditional flood irrigation and mulched drip irrigation and found that mulched drip irrigation promoted the root growth of cotton and improved the production of fine roots after the full-boll stage. The boll number per plant and yield were increased with mulched drip irrigation.

Drip irrigation has been found to be the most effective water-saving system. It can conserve soil, aggregate structure, successfully prevent deep water loss and surface water loss, and therefore, decrease exposure of the soil to degradation and salinization [38][39][40][41]. Fereres et al. [42] reported that an early and increased cotton yield could be achieved by drip irrigation. Mateos et al. [43] stated that drip irrigation was more beneficial than furrow irrigation. In the same line, Ibragimov et al. [44] in Uzbekistan reported that, with drip irrigation used for cotton production, 18–42% of the irrigation water was saved in contrast to furrow irrigation. According to Ward and Pulido-Velazquez [45], compared to flood irrigation, drip irrigation increased cotton yields by about 25% and helped to save water by 40–50%. In the Harran Plain in Turkey, Cetin and Bilgel [21] found that drip irrigation improved seed cotton yield by 21 and 30% over furrow and sprinkler irrigation, respectively. Similarly, in the Texas High Plain, Colaizzi et al. [46] showed that SDI had the best cotton productivity and gross returns, followed by LEPA and spray irrigation. However, Cetin and Kara [15] reported that the use of SDI is limited, because it has adverse effects on cotton seed germination, if during sowing there is no moisture in the soil. For this reason, an alternative irrigation technology, such as sprinkler irrigation, is advised for better cotton germination.

Field-based studies are critical to identify a technology that can provide an optimum yield and quality of cotton, and, at the same time, maximize water-use efficiency.

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