Understanding Cotton Irrigation Management

Subjects: Agricultural Engineering
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A change in climate as well as a decrease in water resources, calls for efficient irrigation-water management in cotton-production systems. Cotton (Gossypium sp.) is an important cash crop in many countries. However, the crop is sensitive to limited water, especially during the flowering stage and appropriate irrigation scheduling is needed depending upon location, climatic conditions, and irrigation method and regimes. Future studies on Kc, cotton water use and evapotranspiration, optimum population, the timing of irrigation termination (IT) in each location are needed for resource use efficiency.

Keywords: Irrigation ; Water management ; Cotton production

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1. Introduction

Cotton is a valuable, natural-textile fiber and the purest source of cellulose [1]. 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 [2] estimated that cotton fiber contributes to half of the world’s clothes.

Recent studies found significant impact of drought and water stress on cotton production has resulted in a reduction in yield and yield components [3-7]. Therefore, different irrigation systems have been developed and used for cotton production across the world with various results. In this review, we look at study outcomes related to irrigation-water practices under full and deficit irrigation, as well as rainfed conditions, using different irrigation methods. The effects on yield and yield components and water-use efficiency are considered. Although the results from different studies are affected by specific management practices, this review mainly focuses on irrigation-water management and its impact on cotton.

2. Cotton Crop Coefficient

The crop coefficient (Kc) is the ratio of actual crop evapotranspiration to the reference crop evapotranspiration. The Food and Agricultural Organization (FAO) of the United Nations has established a crop coefficient for cotton at different stages of growth that can be applied across the globe and presented it in the FAO-56 paper [8]. Nonetheless, various studies determining local Kc values obtained for various developmental stages have been different from those listed in the FAO-56 paper [9-12]. Therefore, the use of the FAO Kc values has resulted in an important difference between estimated and actual crop evapotranspiration (ETc) [11,13]. FAO Kc underestimates or overestimates cotton water requirement in some part of the world.

Studies highlight the spatiotemporal variation of the crop coefficient values. Therefore, for efficient irrigation planning, it is important to develop a local Kc experimentally that characterizes local climate, water requirement, and cotton management practices.

3. Cotton Water Use and Evapotranspiration

Knowledge of water use and crop evapotranspiration (ETc) is crucial for a reliable irrigation scheduling. Many studies have examined the water requirement of cotton in different parts of the world [9,11,14,15]. Results have shown that the water requirements vary from 700 to 1200 mm during the growing season, depending on the season length, climate, cultivar, irrigation method, and production goals [16]. Cotton water use gradually increases from the initial stage, reaches maximum at the mid-season stage, and then steadily declines until the end of the season.

In summary, cotton water use depends on the local climate, the agronomic characteristics of the cotton varieties, crop management practices, and irrigation methods and regimes. Local research on cotton water use is important for better water management.

4. Cotton Water-Use Efficiency

The concept of water-use efficiency (WUE) was introduced more than 100 years ago by Briggs and Shantz [17] indicating a relationship between plant productivity and water use. Cotton lint yield is found to rise with increasing crop water use [18]. Hatfield and Dold [19] defined WUE as the quantity of assimilated carbon in terms of biomass or grain per unit of water used by the crop. 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. 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. Similarly, Evett et al. [16] 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. [20] 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 [21].

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. 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.

5. 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 [22]. Therefore, irrigation is necessary for cotton production. 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. 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 [23-26]. However, Cetin and Kara [21] 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.

Many studies have shown the importance of other irrigation methods, aside from drip irrigation, to achieve the best cotton yield. Lyle and Bordovsky [27] found that LEPA performed better than furrow and sprinkler delivery systems. Based on the above studies, it is seen that irrigation technologies have diverse results under different climatic conditions. 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.

6. Response of Cotton Physiological Traits, Yield, and Yield Components to Irrigation Regimes

Among biotic and abiotic stresses, drought is the most harmful for plant growth and productivity. Across the globe, different irrigation regimes have various effects on cotton physiological traits, yield, and yield components. Water-limited conditions affect the transpiration and the photosynthetic rates of cotton, which then limit the yields. Water stress decreases the leaf area of cotton.

The effect of water stress on cotton seed yield and yield components has been examined by various researchers and has shown a decrease in yield due to water stress. Water stress reduces the transpiration rate, leaf area, and photosynthetic activities in the cotton plant and indirectly reduces yield and its components. The flowering stage of cotton is found to be more sensitive to water stress than the vegetative one. For instance, under field conditions, Kar et al. [28] examined cotton response to limited water and found that water stress at the flowering stage reduced the yields. Fiber quality is a key element in the profitability of cotton, and many researchers have studied the effect of water stress on the quality of cotton fiber. Germination is also affected by the irrigation regime. With alternating periods of water stress during the vegetative period, Mohamed et al. [29] found that Roselle (a species of *Hibiscus*) exhibited a higher tolerance to water stress than with constant water stress; therefore, alternating wet and dry periods is an appropriate water management for Roselle production.

However, some other studies have demonstrated that cotton has drought resistance. In fact, Mitchell-McCallister et al. [30] revealed that deficit or reduced irrigation (RI) is an adaptive management practice that can increase water productivity and result in water conservation. Chen et al. [31] concluded that in arid areas deficit-irrigated cotton, given 425-mm water and grown under a plant density of 36 plants per m^2, had advantages in terms of saving water and energy without yield penalties.

In summary, studies have found mixed results concerning the response of the physiological traits of cotton and its yield and yield components to different irrigation regimes. This is in line with Feng et al. [32] who reported an influence of location on the response of cotton yield and fiber quality to irrigation, which indicates the need to conduct local field studies. Similarly, many reports have emphasized the need to conduct field studies to evaluate crop response to different levels of water stress [33,34]. The findings of the effects of deficit irrigation on cotton performance can assist producers to make better decisions on the suitable levels of deficit irrigation that will produce their yield objectives [35]. There is a critical need to identify and test approaches that optimize water use for cotton production systems.

7. Cotton Yield and Yield Components in Response to Plant Density

Plant density is an important abiotic factor affecting cotton production [36] and has been evaluated in a number of studies [37-40]. According to Ajayakumar et al. [41], an appropriate spacing between plants is an essential agronomic factor that influences optimal use of resources for increased crop productivity. Many studies have reported the adverse effect of using high planting densities in cotton production systems. The use of high planting densities enhances the emergence of diseases, the appearance of smaller bolls, the shading of immature flowers, lateness in maturation, and a decline in plant size [39,42]. On the other hand, several studies have found the importance of high cotton plant densities. Khan et al. [43] revealed that dense plants enhanced plant total biomass, but the individual biomass of a cotton plant was reduced.

Based on the above research results, plant density has a direct relationship with cotton yield and yield components. Optimum yield, through better management practices, is the goal of cotton agronomists. Optimum plant density is found to vary with various conditions, such as the climate, the genotype and irrigation method used, and soil characteristics. Therefore, it is important to carry out studies in each geographic area to identify the optimal sowing density for maximum yields.

8. Irrigation Termination in Cotton Production

While cotton yield and fiber quality are affected by rainfall and irrigation events [44-47], irrigation termination remains a critical decision in cotton production. Many studies across the globe have linked irrigation termination (IT) to cotton yield, yield components, and resource-use efficiency. Results have varied according to the local environment, soil characteristics, water availability, irrigation strategies, and genotypes used. Studies have pointed out the benefits of early IT without affecting yield. Other studies have found controversial results on the contribution of early IT by presenting the importance of late irrigation to maintain yield and its components. Because irrigation termination has temporal and spatial contradictory effects under different environmental conditions, one approach is to optimize the IT timing, which could be a key factor in cotton irrigation water management.

While early IT could induce yield losses, late IT also could waste valuable irrigation water without any extra yield, delay harvest, and increase the costs of management of insects and disease pests [48-50]. An appropriate date for final irrigation, which may save water and accelerate boll maturity without yield penalty [51], must be determined by the producers. Divergent results in different zones call for further studies concerning the effects of IT on cotton yield. As suggested by Lascano et al. [52] and Vories et al. [53], the optimum IT for cotton could improve farmers' management practices and, more importantly, support water-saving endeavors in arid and semiarid areas.

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