ECONOMIC ANALYSIS OF MODERN IRRIGATION SCHEDULING STRATEGIES ON COTTON PRODUCTION UNDER DIFFERENT TILLAGE SYSTEMS IN SOUTH GEORGIA

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Abstract

Cotton growers in Georgia use irrigation as a risk management tool to mitigate production risks. To improve the efficiency of water usage, various irrigation scheduling methods were developed with the goal of increasing cotton yield and saving water. The objective of this study is to compare economic efficiency of five different irrigation scheduling methods (UGA checkbook method, smart irrigation cotton app, UGA smart sensor array, cotton water stress index, and irrigator pro) under conservation and conventional tillage practices. Field experiment data were collected from 2013 to 2017 for estimating irrigation water use efficiency (IWUE) and net return per acre for each of irrigation scheduling methods. Results indicated that modern irrigation scheduling methods were more efficient than calendar based UGA checkbook method. For dry year like 2014, IWUE were found to be positive for all irrigation scheduling methods and cotton app was most efficient method in term of net return per acre for both tillage practices. But for wet years (2013, 2015, 2016 and 2017), most of the irrigation scheduling methods showed negative IWUE values. UGA checkbook method resulted in significantly lower net return in wet years than other modern irrigation scheduling methods. For all years, cotton app was found to be the most economically efficient irrigation scheduling method with average net return of $870/acre for conservation tillage and $845/acre for conventional tillage.

Introduction

In Georgia, cotton production is mainly concentrated in the southern part of the state. In 2019, Georgia farmers planted 1.4 million acres of cotton, with an average yield of 915 pounds per acre (USDA-NASS, 2019). About 50% of the cotton acres planted in Georgia are irrigated acres. Cotton growers use irrigation to reduce production risks caused by uncertainty in weather conditions. This increasing demand for irrigation water is depleting the ground water level. If the rate of pumping is greater than the rate of recharging capacity of the aquifer, aquifer capacity can be permanently damaged leading to decreased water quality, ground subsidence and other problems.

Developing innovative irrigation scheduling methods, which reduce water usage while achieving higher yields and profitability, should be the focus of today's world. As cotton mostly need water during flowering and boll maturation, scheduling irrigation according to the needs of the plants can lower water stress in cotton as well as can reduce the amount of irrigation water. But only about 20% cotton growers in the U.S. adopt scientific irrigation scheduling methods. The majority of farmers in Georgia rely on calendar based methods and the visual symptoms for irrigation. This usually result in either under irrigation or over irrigation and both of them can cause significant yield losses. Over irrigation may lead to excessive vegetative growth and fewer photosynthates for the growing flowers, and thus lower the yield potential (Grimes 1994, Karam et al. 2006, Wanjura et al. 2002). A deficit irrigation scheduling system was found to be more efficient than the full irrigation scheduling system (Grove and Oosthuizen 2010). However, farmers are not willingly opting to save water by using deficit irrigation scheduling system instead would expect some compensation for choosing that (Grove and Oosthuizen 2010).

To reduce water usage, increase water use efficiency, and improve yield and overall sustainability of the production system, several irrigation scheduling methods are developed. In this research, six irrigation scheduling methods were compared, including UGA checkbook method, smart irrigation cotton app, UGA smart sensor array, cotton water stress index, irrigator pro, and dryland control. Various studies have been carried out to investigate the most economical, sustainable, and efficient irrigation scheduling methods that can escalate the production as well as save water. Economic analysis of the irrigation scheduling systems for corn production revealed that advanced irrigation scheduling system could decrease energy and water usage, while improving profitability (Kranz, Eisenhauer, and

Retka 1992, Epperson, Hook, and Mustafa 1993, Lecina 2016, Vatta et al. 2018). The main objective of this study is to compare the economic efficiency of different irrigation scheduling methods under different tillage practices and identify the most profitable irrigation scheduling method.

Methods

Irrigation Scheduling Methods

Cotton water stress index (CWSI) evaluates plant's water stress with the help of infrared sensors. These sensors depict the temperature of the leaves, and stressed leaves have higher temperature. Irrigation is provided after the stress is observed on the leaves (Jensen et al. 1990). The UGA checkbook is a calendar based method which is most common among the growers. There are weekly requirements of water for the cotton after the first bloom. Daily rainfall data are measured with rain gauzes that are subtracted from the weekly requirements to get the amount of irrigation. Table 1 shows the weekly requirements of water for the cotton after the first bloom. The UGA checkbook method does not consider the available soil moisture hence may result in over-application of water in the field.

Table 1**:** Irrigation recommendation by UGA Extension for cotton

Crop Stage	Inch/week
Week of first bloom	1.02
2nd week	1.52
3rd week	2.03
4th week	2.03
5th week	1.52
6th week	1.52
7th week	1.02

The University of Georgia Smart Sensor Array (Vellidis et al. 2013, Liakos et al. 2017) system accounts for the available soil moisture in the soil. Soil sensors are installed at different depths which send hourly soil moisture readings to the base station. The soil moisture information is uploaded to a server and later on converted to the volumetric water content for recommending the amount of irrigation needed for the field.

The Smart Irrigation Cotton App (Cotton App) is an evapotranspiration (ET) based irrigation scheduling method using deficit irrigation. Meteorological data, soil parameters, crop phenology, crop coefficients, and irrigation application are used to estimate the moisture deficit in the effective root zone of the cotton plant. Users can download the app on their smart phones and input the information of location, soil type and irrigation type to get amount of water to irrigate and time to irrigate (Vellidis et al. 2016). Irrigator Pro is another app based scheduling method that estimates available soil water content and needs soil water tension data from two different depths (8.5 inch and 16 inch). Irrigation is applied after the soil water tension exceeds specific threshold.

Experiment Description

Data from a five-year of field experiment for cotton were used for this research. The experiment was conducted at C.M. Stripling Irrigation Research Park located in Camilla, Georgia from 2013 to 2017. Complete randomized block split plot experimental design was used with three replications for each treatment. There were 27 plots (15.2m long × 1.8 m wide) each for 2013, 2015, 2016 and 2017 and 21 plots for 2014. Table 2 includes all the treatments for different years. Except for dryland control, which was conducted on conservation tillage, the other irrigation scheduling methods were tested for both conservation and conventional tillage practices.

Table 2: Different treatments for each year. Figures in parenthesis beside the years are the rainfall amount in inches for respective year. Figures in parenthesis beside the scheduling methods are the irrigation amount in inches.

2013 (27.4)	**2014 (11.2)**	**2015 (22.6)**	**2016 (25.6)**	**2017 (24.3)**
Control (1.5)	Control (3.8)	Control (0.5)	Control (0.75)	Control (0.5)
Checkbook (12.7)	Checkbook (15.2)	Checkbook (6.5)	Checkbook (8)	Checkbook (9.5)
Cotton App (3.0)	Cotton App (9.1)	Cotton App (5)	Cotton App (5.25)	Cotton App (4.5)
	UGA SSA with 50 kPa constant threshold (14.6)	UGA SSA with 50 kPa constant threshold (7.25)	UGA SSA with 50 kPa constant threshold (3.25)	UGA SSA with 50 kPa constant threshold (4)
		UGA SSA with variable threshold (4.25)	UGA SSA with variable threshold (2.76)	
Irrigator Pro (2.2)				Irrigator Pro integrated with the UGA SSA (2.5)
CWSI (4.5)				

Irrigation Water Use Efficiency (IWUE)

IWUE represents the additional amount of cotton produced for each inch of irrigation of an irrigation scheduling method ($treatment$) compared to the dryland control ($control$). It can be calculated as,

$$IWUE = \frac{Yield_{treatment} - Yield_{control}}{Irrigation_{treatment} - Irrigation_{control}} \quad \text{(lbs acre}^{-1}\text{ inch}^{-1}\text{)}$$

Economic Analysis

After the harvest from each plots, lint yield were obtained. The market price of cotton was adjusted for the differences in the premiums or discounts for different fiber quality and gross revenue was obtained as following,

$$Gross\ Revenue = Lint\ Yield\ \times Lint\ Price + Seed\ Yield\ \times Seed\ Price$$

Ginning costs and harvesting costs were calculated for each irrigation scheduling methods. UGA Extension irrigation budget was used to estimate the irrigation costs. Irrigation budget estimates the ownership costs and operating costs of each irrigation scheduling systems. Total Expenditure was calculated as,

$$Total\ Expenditure = Cost\ of\ Irrigation + Harvesting\ Cost + Ginning\ Cost$$

Finally, net return for each irrigation scheduling methods was then obtained from the difference of gross revenue and total costs as follows,

$$Net\ Return = Gross\ Revenue - Total\ Expenditure$$

RStudio Version 1.2.5001 was used to conduct analysis of variance (ANOVA) for net returns of each irrigation schedules. Tukey tests were done to find the significance differences among the schedules at 95% confidence level. Significance difference was observed within the irrigation schedules of a tillage practices and not between the tillage practices.

Results

Due to El Nino phenomenon, 2013 and 2015 had higher precipitation of 27.4 and 22.6 inch respectively (Nuccitelli 2014, Sumner, 2016). 2016 (25.6") and 2017 (24.3") also received higher rainfall and were all regarded as wet years. In 2014, however, lack of tropical systems coming up from the Gulf of Mexico (Thompson and Beckham, 2014) resulted in lesser precipitation of about 11.2 inches making it a dry year.

IWUE

Positive IWUE value was seen only in dry year. The result of the IWUE for the year 2014 is shown in Figure 1. This showed that irrigation can be very efficient and yield better if there is less preexisting moisture in the field. This supports the finding of the past research regarding the higher yield of cotton lint resulted from the irrigated condition than the dryland regime during the dry years (Sorensen and Lamb 2019). From the figure, cotton plant is producing more if they are irrigated by using deficit irrigation based cotton app. This coincides with previous studies of deficit irrigation having higher water use efficiency (Jalota et al. 2008, Ünlü et al. 2011, Fan, Wang, and Nan 2018).

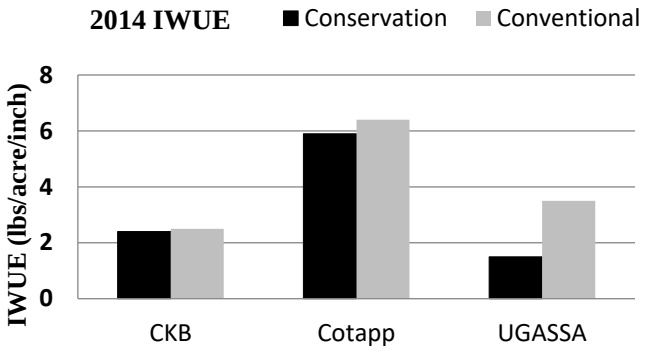

Figure 1: IWUE (lbs acre^{-1} inch^{-1}) for each irrigation scheduling treatments in 2014 under both conservation (dark black) and conventional (faint black) practices. CKB, UGA checkbook method; Cotapp, Cotton app; UGASSA, UGA SSA with 50 kPa constant threshold.

Figure 2 portrays the IWUE for 2015, a wet year. All the irrigation scheduling methods resulted the negative IWUE with highest negative value for UGA SSA with variable threshold. For other wet years the results were similar. Over irrigation during wet years wasted water and reduced yield. Vellidis et al. (2016) concluded that in wet years, rain-fed field resulted higher water use efficiency than other irrigation scheduling methods and this is consistent with our results.

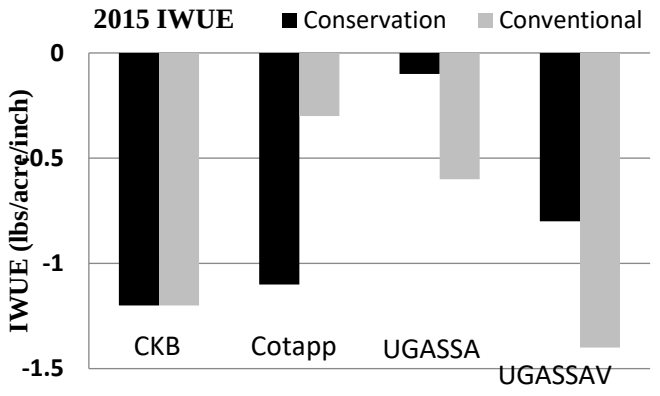

Figure 2: IWUE (lbs acre^{-1} inch^{-1}) for each irrigation scheduling treatments in 2015 under both conservation (dark black) and conventional (faint black) practices. CKB, checkbook method; Cotapp, cotton app; UGASSA, UGA SSA with 50kPa constant threshold; UGASSAV, UGA SSA with variable threshold

Net Return

Net return for 2013 (figure 3) showed that there was no significant difference among the scheduling methods within the tillage practices. In conservation tillage, highest net return of $1,165 per acre was obtained from dryland control and checkbook method resulted lowest net return of $948 per acre. For conventional tillage, the highest net return was

obtained from cotton app ($1,021/acre) and lowest from checkbook ($795/acre). For wet years like 2015, 2016 and 2017, calendar based checkbook method resulted in significantly lower net return than other modern irrigation scheduling method and dryland control. Table 3 shows the net return and standard deviation for all the irrigation scheduling treatments in 2015 and 2016. Similarly, table 4 is for 2017.

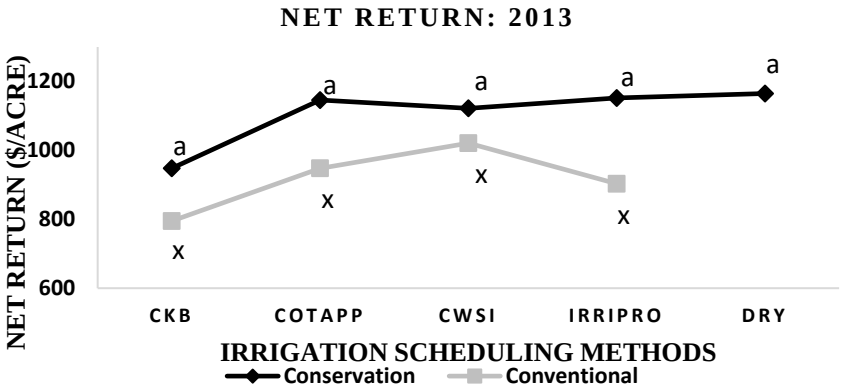

Figure 3: Net return ($/acre) for all irrigation scheduling treatments of 2013. CKB, checkbook method; COTAPP, cotton app; CWSI, cotton water stress index method; IRRIPRO, irrigator pro; DRY, dry land control. Net returns with same *t* grouping letters are not significantly different.

Table 3: Net return ($/acre) for 2015 and 2016. Net returns with same *t* grouping letters are not significantly different. Figure in parenthesis is standard deviation.

Irrigation Schedules	2015		2016	
	Conservation	Conventional	Conservation	Conventional
CKB	765.68[a] (111.96)	758.14[a] (146.01)	406.5[a] (53.27)	253.40[a] (162.28)
COTAPP	800.51[ab] (114.08)	846.54[a] (128.35)	597.07[ab] (156.27)	586.39[b] (183.86)
UGASSA	872.75[ab] (93.99)	788.38[a] (143.91)	614.90[ab] (193.11)	695.67[b] (78.94)
UGASSAV	820.81[ab] (98.63)	805.82[a] (110.61)	693.75[b] (77.00)	670.07[b] (58.21)
DRY	898.26[b] (129.32)		722.51[b] (107.70)	

This revealed that if there is enough precipitation during the growing season for cotton, additional irrigation is detrimental to the yield and profitability. Results also indicate that using modern irrigation scheduling methods is better than the calendar based checkbook method during wet years.

Net return for 2014 is shown in figure 4 and significant difference was seen between checkbook and control, cotton app and control and cotton app and UGA SSA for conservation tillage. However, for conventional tillage there were no significant difference among the scheduling systems. For both tillage practices, cotton app yielded highest net return and dryland control resulted the lowest. This showed that in dry year the cotton app is economically efficient irrigation scheduling method.

Table 4: Net return ($/acre) for 2017. Net returns with same *t* grouping letters are not significantly different. Figure in parenthesis is standard deviation.

Irrigation scheduling methods	Conservation	Conventional
CKB	613.05[a] (65.13)	584.05[a] (107.53)
COTAPP	806.29[b] (73.15)	795.54[a] (81.07)
PROUGASSA	819.28[b] (77.67)	650.41[a] (180.33)
UGASSA	781.17[b] (33.22)	739.38[a] (103.13)
DRY	827.19[b] (52.72)	

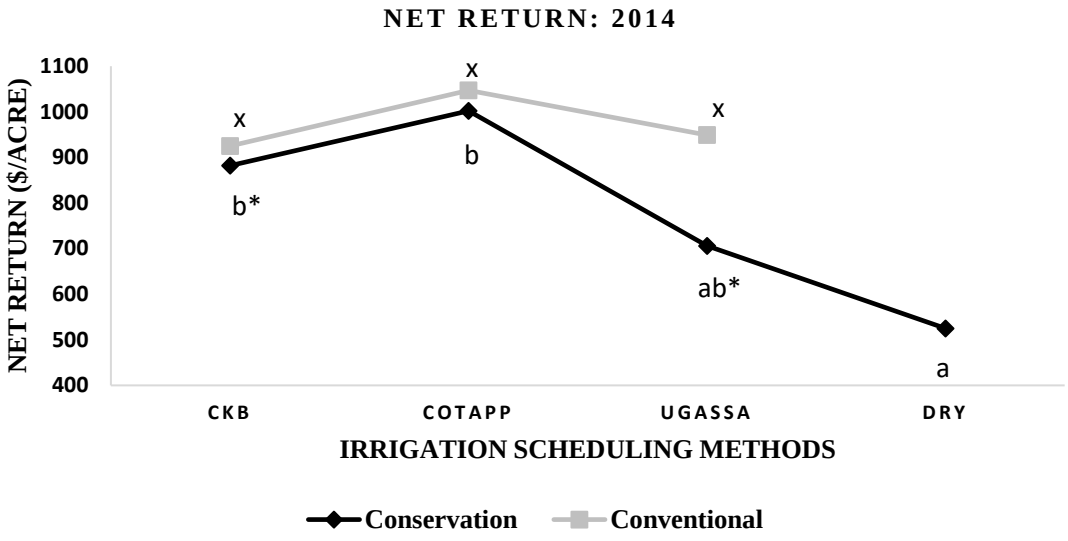

Figure 4: Net return ($/acre) for all irrigation scheduling treatments of 2014. CKB, checkbook method; COTAPP, cotton app; UGASSA, UGA SSA with 50 kPa constant threshold; DRY, dry land control. Net returns with same *t* grouping letters are not significantly different.

Summary

Five different irrigation scheduling methods were compared for their water use efficiency, yield and profitability for five years (2013 to 2017) in this study. Irrigation water use efficiency index was found to be positive for dry years and negative for wet years. The IWUE was found negative for all the irrigation scheduling methods in wet years. It will be better for growers to not add extra water through irrigation if there is already enough rainfall in the growing season. Economic analysis showed that in dry years, irrigation increased yield and profitability. Net return from cotton app was significantly higher than UGA SSA and dry land control. Whereas, in wet years, irrigation hurt yield and profitability. It was more profitable for growers to use modern irrigation scheduling methods rather than calendar based irrigation scheduling methods like UGA checkbook.

Cotton app was found to be economically efficient irrigation scheduling method with the average net return of $870/acre for conservation tillage and $845/acre for conventional tillage. The use of advanced irrigation scheduling tools can increase farmer's profitability and water use efficiency.

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