ECONOMIC RISK ANALYSIS OF MODERN IRRIGATION SCHEDULING METHODS ON COTTON PRODUCTION IN GEORGIA

by

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(Under the Direction of Yangxuan Liu)

ABSTRACT

With the increment in population and demand for foods and fibers, the available resource, such as water is facing the big challenge of scarcity. In agriculture, growers use irrigation to minimize the risks associated with production variability, which puts further pressure on water availability. The scientific world has been focused on developing modern irrigation scheduling techniques, which can increase water use efficiency, at the same time, enhance the production, and save the water. However, the adoption of new technologies is low among growers because they are unbeknownst of the economic return and risk associated with these new technologies. This study evaluated the economic efficiency of several modern irrigation scheduling methods in cotton production, and conducted risk analysis of two major irrigation schedules, which are the UGA checkbook method and the smart irrigation cotton app. Results from both analyses show that modern irrigation schedules are more economically efficient than conventional methods.

INDEX WORDS: water use efficiency, smart irrigation, net return, risk efficient

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Water is a renewable natural resource and is generally thought to be abundant. However, as an essential life component, the freshwater is limited (Pimentel et al., 1997). Several human activities combined with population growth have resulted in a decrease in the amount of freshwater, or, more often, degraded its quality (El-Zeiny and El-Kafrawy, 2017, Owa, 2013). One such activity is agriculture. As the major consumer of water (Molden, 2007), agriculture provides foods, fibers, and raw materials for the industrial sector. It is estimated that the population will rise by 65%, and around two-thirds of the world's population will face water scarcity by 2050 (Wallace, 2000). Therefore, agriculture is bound to face the greatest challenge after the water scarcity at its peak. However, according to a survey conducted by the U.S. Department of Agriculture (USDA), the majority of the growers in the United States do not use any of modern irrigation methods (USDA, 2018). The calendar-based irrigation method, the feel of the soil method, irrigating when the neighbors irrigate, and irrigation after visual symptoms on plants are the most adopted methods by the growers (USDA, 2018). These methods do not consider the available soil moisture present in the soil and mostly result in over-irrigation.

Previous study has shown that only 10-30 % of irrigation water is withdrawn by the plants (Wallace, 2000), suggesting that a large amount of water can be saved if appropriate irrigation techniques following reduced irrigation concepts are adopted. More accurate timing and amount to irrigate plays a vital role in improving water use efficiency for agricultural production. Hence, several modern irrigation scheduling methods are invented to increase the precision of water application, water use efficiency, and yield. These modern irrigation scheduling methods allow growers to determine the exact time and the precise amount to irrigate. The economic profitability is expected to be higher, as less amount of water is utilized in these methods.

However, limited research has been conducted on estimating the economic profitability and risk associated with modern irrigation scheduling methods. Without this information, the adoption rate of modern scheduling methods remains low among risk-averse growers (USDA, 2018). This study evaluated the economic efficiency and risk associated with modern irrigation scheduling methods for cotton production. The goal of this research is to help cotton growers to make more informed decisions in their adoption of modern irrigation methods.

1.2 THESIS FORMAT

This research investigates three main objectives related to irrigation scheduling methods. First, the irrigation budgets estimating irrigation costs associated with three major irrigation scheduling systems, the checkbook, the soil moisture sensor based system (SMS plus), and the app based methods, will be discussed. Second, this research compares the economic profitability of five different irrigation scheduling methods. Third, this research conducts risk analyses of two main irrigation scheduling methods, which are the UGA checkbook method (Checkbook) and the smart irrigation cotton app (Cotton App), and compares these two methods with respect to the dryland control (Control).

The second chapter of the thesis gives a short description on the four different UGA irrigation budgets. There are two irrigation budgets for center pivot operated by diesel engine (covering 65 acres and 160 acres), and two irrigation budgets for center pivot operated by electric engine (covering 65 acres and 160 acres). The irrigation budget is used to estimate the ownership and operating costs associated with the irrigation scheduling systems.

The second objective will be addressed in the third chapter. The net return above irrigation costs and harvesting costs (net return per ha) will be identified for each irrigation scheduling methods. Chapter four quantifies the risks associated with the irrigation scheduling methods in the third objective using certainty equivalent (CE) and utility weighted risk premiums (RP).

CHAPTER 2 OWNERSHIP AND OPERATING COSTS OF IRRIGATION THROUGH IRRIGATION BUDGETS IN SOUTH GEORGIA[1]

[1] Bhattarai, A. To be released on University of Georgia Extension website.

2.1 ABSTRACT

Irrigation is a tool for managing production risk in row crop production in South Georgia. Irrigation, which is widely adopted by row crop producers in the state, enables them to generate higher and more consistent yields than non-irrigated production. Even with the likelihood of increased yield, there are additional costs associated with owning and operating an irrigation system. Costs associated with owning an irrigation system are the fixed costs that include the depreciation, intermediate interest, and tax & insurance costs. Operating costs are the variable costs, including costs of operational energy, repairs and maintenance, and labor costs. To help producers estimate their costs, four center pivot irrigation budgets were created: two for a pivot covering 65 acres and two for a pivot covering 160 acres, with either an electric or diesel energy source. Each budget is based on a spreadsheet using Microsoft Excel. The spreadsheet is comprised of three main parts: total investment costs, annual ownership costs (fixed cost), and annual operating costs (variable cost) per acre. The budget calculates the annual operating costs in per acre inch basis. The total annual cost of the irrigation system is the summation of annual ownership costs and annual operating costs. The default values in the budgets can be modified to reflect investment and energy costs specific to the individual producer to help them more accurately estimate their costs.

2.2 OVERVIEW

Irrigation is widely adopted for managing production risk in row crop production in South Georgia. Even with the likelihood of increased yield, there are additional costs associated with owning and operating an irrigation system. Irrigation budgets developed by the University of Georgia Extension help producers to estimate total investment costs, annual ownership costs (fixed costs), and annual operating costs (variable costs) per acre. Four irrigation budgets are developed in Microsoft Office Excel, including a pivot covering 65 acres with electric irrigation system, 65 acres with diesel irrigation system, 160 acres with electric irrigation system, and 160 acres with diesel irrigation system. The irrigation budget for diesel operated center pivot has a gearhead system, while the electric operated center pivot has a power unit.

The irrigation budgets consist of information, as shown in Figure 1, regarding the number of pivots on the farm, the number of towers, the acreage covered, the time needed for completing a full circle, crop type, the type of irrigation scheduling method, and the acre inch applied. The number of pivots on a farm is estimated by dividing the average farm size by the acreage covered by the pivot in the budget. The data for average farm size for irrigated acres in Georgia (Table 1) comes from 2017 Census of Agriculture. The number of pivots on a farm is assumed to be 4 for 65 acres irrigations systems, and 2 for 160 acres irrigation systems in the budgets, but it can be customized by the users. The acreage irrigated and hours to complete a full circle depend upon the number of towers and length of each span.

Table 1: Average Farm Size for Irrigated Acreage in Georgia

Row Crops	**Number of farms**	**Irrigated Acreage**	**Average Farm Size**
Corn	891	146480	164
Cotton	1371	434548	317
Peanut	1558	364427	234
Total	**3820**	**945455**	**248**

Source: 2017 Census of Agriculture. Volume 1, Chapter 2: State Level Data, Table 25

Users can select the type of crops (Figure 2: corn, cotton, and peanut), and the type of irrigation scheduling method (Figure 3: checkbook, SMS plus, and app based) from the dropdowns as shown in the following figures.

160 Acre Electric Engine Center Pivot Irrigation Budget Georgia, 2020	
No. of Pivots on Your Farm	2
No. of Towers per Pivot	8
Acreage Covered (Acres)	160
Hours for Full Circle (Hours)	73
Crop Type	Corn
Irrigation scheduling Method[1]	Checkbook
Acre Inch Applied (Inch)	12

Figure 1: Features of irrigation budget for 160 acres electric center pivot.

No. of Pivots on Your Farm	2
No. of Towers per Pivot	8
Acreage Covered (Acres)	160
Hours for Full Circle (Hours)	73
Crop Type	Corn Corn Cotton Peanut
Irrigation scheduling Method[1]	
Acre Inch Applied (Inch)	

Figure 2: Dropdown for crop type.

No. of Pivots on Your Farm	2
No. of Towers per Pivot	8
Acreage Covered (Acres)	160
Hours for Full Circle (Hours)	73
Crop Type	Corn
Irrigation scheduling Method[1]	Checkbook Checkbook SMS Plus App Based
Acre Inch Applied (Inch)	

Figure 3: Dropdown for irrigation scheduling type.

Checkbook is a calendar-based irrigation scheduling method. SMS plus uses soil moisture sensors in the field, as shown in Figure 4. Soil moisture sensors read the amount of soil moisture present in the field and send the data to the base station. The base station collects the soil moisture information and converts them into volumetric water content to determine the amount of irrigation water needed. Generally, each farm only needs one base station.

There are two types of soil moisture sensors available in the market: tensiometric sensor and capacitance sensor, as shown in Figure 4. The tensiometric sensor uses soil moisture tension, also known as matric water potential. These sensors require a longer time to give the result of available soil moisture. The capacitance sensor uses several probes to measure the soil moisture. Sensors are distributed along with the probe that determines the changes in the soil water content. These sensors can precisely measure the soil water content within a short period to guide more precise irrigation scheduling decisions. Even though the capacitance sensor is more accurate, the cost of the capacitance sensor is higher than the tensiometric sensor. Consequently, the tensiometric sensor is more widely adopted by farmers than the capacitance sensor. Thus, in our irrigation budget, we assume that farmers use the tensiometric sensor.

Figure 4: Sensors based system including tensiometric system (Top) and capacitance system (Bottom).

The app-based method (Figure 5) refers to a crop-specific app that can be downloaded in smartphones for free. Users need to enter the information regarding the location of the field and soil types after download at their first use of the app. Then, the app-based method estimates the amount of irrigation water need for the field based on the corresponding meteorological data, crop phenology, and crop coefficient.

Figure 5: Cotton App developed by Vellidis et al.

Investment costs, annual ownership costs, and annual operating costs changes with the type of crops and irrigation scheduling method used. The default value for the acre inch applied in our irrigation budget varies with different crops and different irrigation scheduling methods. These default values of irrigated inches (Table 2) are based on field experiments conducted by agricultural engineers at the University of Georgia. Users can also input their own acre inch applied into the irrigation budget according to their farming records. For each crop, users can choose the checkbook method if they have a calendar-based irrigation system, SMS plus if they use soil moisture sensors, and app-based if they use a smart irrigation app to irrigate the field.

Table 2. Irrigation depth for each crop and irrigation system during the growing season.

Irrigation Scheduling Methods	Corn	Cotton	Peanut
Checkbook	12	10	13
SMS Plus	10	4	6
App Based	10	5	7

Unit: Per Acre Inch.

2.3 COMPONENTS OF IRRIGATION BUDGETS

There are three major components in the irrigation budget, including total investment costs, annual ownership costs (fixed cost), and annual operating costs (variable cost) per acre. The following illustrates the components of the irrigation budget using the electric irrigation system.

2.3.1 Investment Costs

The cost of pipe and fittings, the pivot system, power unit (for electric), gearhead system (for diesel), well, and the pump, along with their installation costs are the major portions of the investment costs. Besides this, the cost of soil moisture sensors and base station are added when the users select the SMS plus irrigation scheduling method.

Salvage value is the expected market value of the asset at the end of its assigned useful life. Useful life is the number of years the asset is expected to be used. The difference between the investment cost and salvage value is the total depreciation or loss in value expected over the useful life. Users can adjust the assumptions made for the useful life and the salvage value of the asset. The default salvage values of the equipment are assumed to be zero in the irrigation budgets.

The cost of the well depends on the depth and size of the well. In South Georgia, depends on the location, water can be pumped from the Floridan Aquifer (60-600 feet) or the

Claiborne Aquifer (700 + feet). Mostly farmers draw water from the Floridan aquifer. However, in certain regions, new well can only be installed to pump water from the Claiborne Aquifer due to current water regulations. The assumption in this budget for the well is an 8-inch 500 feet open hole well with casing up to 300 feet. The pumping capacity is 1000 gallons per minute. The costs for the pump, power unit, and well are quoted by calling the drilling companies in South Georgia.

If the user chooses the SMS plus option, the budget will automatically add the extra costs for the soil moisture sensors and the base station. We assume an average number of 4 pivots per farm for the 65 acre budget and 2 pivots for the 160 acre budget, and each farm only needs one base station. Thus, the investment cost for the base station is adjusted with the number of pivots on the farm. However, users can change this value according to the number of pivots they own on their farm.

Investment Costs						
	Useful Life	Salvage Value	Quantity	Cost/Unit	Investment Cost	Investment Costs Per Acre
Pipe and Fittings (Feet)	20	0	500	$7.75	$3,875.00	$24.22
Pivot System	20	0	8	$12,000.00	$96,000.00	$600.00
Installation			1	$9,500.00	$9,500.00	$59.38
Pump	15	0	1	$33,000.00	$33,000.00	$206.25
Power Unit	15	0	1	$17,000.00	$17,000.00	$106.25
Well[2]	20	0	1	$53,000.00	$53,000.00	$331.25
Soil Moisture Sensors	6	0	1	$600.00	$600.00	$3.75
Base Station	6	0	1	$2,000.00	$400.00	$2.50
Total Investment Costs					**$213,375.00**	**$1,333.59**

Figure 6: Investment costs inside the irrigation budget

2.3.2 Ownership Costs

Ownership costs are the annual fixed costs associated with the investment costs. It includes the depreciation costs, intermediate interest costs, tax and insurance costs for pipe and fittings, pivot system, pump, power unit (for electric), gearhead system (for diesel), well, soil moisture sensors, and base station.

Ownership Costs						
		Depreciation[3]	Intermediate Interest[4]	Tax & Insurance[5]	Ownership Costs	Ownership Costs
			8.00%	2.50%		Per acre
Pipe and Fittings		$193.75	$155.00	$48.44	$397.19	$2.48
Pivot System		$4,800.00	$3,840.00	$1,200.00	$9,840.00	$61.50
Pump		$2,200.00	$1,320.00	$412.50	$3,932.50	$24.58
Power Unit		$1,133.33	$680.00	$212.50	$2,025.83	$12.66
Well		$2,650.00	$2,120.00	$662.50	$5,432.50	$33.95
Soil Moisture Sensors		$100.00	$24.00	$7.50	$131.50	$0.82
Base Station		$66.67	$16.00	$5.00	$87.67	$0.55
Total Ownership Costs					**$21,847.19**	**$136.54**

Figure 7: Ownership costs inside the irrigation budget

Depreciation is the annual, noncash expense to recognize the amount by which an asset loses value due to use, age, and obsolescence. It spreads loss in value of the asset over its useful life. The annual depreciation depends upon the investment cost, salvage value, and the useful life of the equipment. The annual depreciation can be computed from the following equation,

$$Depreciation = \frac{investment\ cost - salvage\ value}{useful\ life}$$

Intermediate interest is the fixed cost associated with the irrigation system. Interest is charged to the initial investment and salvage value of the equipment each year throughout their useful life. The intermediate interest rate of the equipment is considered to be eight percent and is calculated as,

$$Intermediate\ interest = \frac{investment\ cost + salvage\ value}{2} \times interest\ rate$$

Similarly, producers have to pay annual taxes and insurance for owning the equipment. Insurance cost is paid to reduce the risks faced by the owner(s) of the irrigation system. The rate for property taxes and insurances are considered to be two and a half percent and are calculated as,

$$Tax\&insurance = \frac{investment\ cost + salvage\ value}{2} \times tax\ \&\ insurance\ rate$$

Users can adjust the intermediate interest rate and the rate for the property taxes and insurances to reflex their own costs. The annual ownership costs are the total costs of depreciation, intermediate interest, and tax and insurance.

$$Annual\ ownership\ cost = depreciation + intermediate\ interest + tax\ \&\ insurance$$

2.3.3 Operating Costs

Operating costs, also called variable costs, changes with the amount of water usage. These costs include fuel or electricity costs, repairs and maintenance costs, and labor and management costs.

		Horse Power	Cost Per Unit ($/kWh)	Total	Operating Costs Per Acre	Operating Costs Per Acre Inch
Electricity		60	$0.13	$5,199.21	$32.50	$2.71
Repairs and Maintenance Costs[6]				$1,225.00	$7.66	$0.64
		Hours	**Cost Per Hour**			
Labor Cost		0.28	$13.25	$7,208.00	$45.05	$3.75
Management Cost		10.00	$34.21	$342.10	$2.14	$0.18
Total Operating Costs				**$13,974.31**	**$87.34**	**$7.28**

Figure 8: Operating costs inside the irrigation budget

Energy costs depend upon the horsepower of the pumps and motors, the cost of gas or electricity per unit, the depth of irrigation applied, and the hours need to complete a full circle. The horsepower of the pump increases with the size of the center pivot system and the field. For diesel-operated systems, fuel cost is calculated; and for electrically operated systems, electricity cost is calculated. Fuel consumption varies based on the engine manufacturer. The depth of irrigation applied varies from season to season and different soil types. In the irrigation budgets, assumptions are made for the average annual depth of irrigations for each of the three irrigation scheduling methods and crops. Energy costs are calculated as,

$$Fuel\ cost = 0.044 \times horsepower \times cost\ of\ fuel\ per\ gallon \times acre\ inch\ applied \times hours\ for\ full\ circle$$

Where 0.044 gals/HP/hr is fuel consumption per hour, which might vary with the different engine manufacturers.

$$Electric\ cost = 0.746 \times horsepower \times cost\ of\ electricity\ per\ unit \times acre\ inch\ applied \times hours\ for\ full\ circle$$

Where 0.746 kW/HP/hr is the power consumption by the equipment per hour.

The cost for repairs and maintenance of the equipment is estimated by multiplying the cost factor of the equipment with its investment cost. The cost factor for the pump in diesel operated system and electricity operated system is assumed to be 6.60 % and 2.00 %, respectively. The cost factors for all equipment are listed in the cost factor sheet of the irrigation budget. The repairs and maintenance costs for each equipment is calculated as,

$$Repairs\ and\ maintenance\ costs = \ initial\ costs\ \times\ cost\ factors$$

In the irrigation budget, total repairs and maintenance costs are calculated by adding together the repairs and maintenance costs for all the equipment used.

Labor cost depends upon the labor hours needed for each acre inch of water applied (labor hours per acre inch), the annual depth of irrigation (acre inch applied), the cost of labor per hour, and the area covered by the pivot. The value for the number of labor hours per acre inch is assumed to be 0.28 hours or 17 minutes. The labor cost is calculated as,

$$\begin{aligned} Labor\ cost &= labor\ hours\ per\ acre\ inch\ \times acre\ inch\ applied \\ &\quad \times cost\ of\ labor\ per\ hour\ \times area\ covered \end{aligned}$$

Management cost estimates the cost for the time spend by the farm manager in using the each of the irrigation systems during the growing season. Management cost depends upon the management hours that a manager spends during the growing season for each pivot and the cost of the manager per hour. The management hours per pivot for different crops and irrigation systems are listed in Table 3. The cost of the manager per hour is $34.21, which is the 2019 median pay for farmers, ranchers, and other agricultural managers from the U.S. Bureau of Labor Statistics. The management cost is calculated as,

$$Management\ cost = management\ hours \times cost\ of\ manager\ per\ hour$$

Table 3. Management hours per pivot for different crops and irrigation systems during the growing season.

Irrigation Scheduling Methods	**Corn**	**Cotton**	**Peanut**
Checkbook	10	12.50	11.67
SMS Plus	15	18.75	17.50
App Based	10	12.50	11.67

Data from Dr. Wesley Porter, Personal Communication, May 20, 2020.

2.3.4 Total Annual Costs

Figure 9 shows the total annual costs of the irrigation budget. The total annual cost of the irrigation system is calculated as,

$$Total\ annual\ costs\ =\ total\ ownership\ costs\ +\ total\ operating\ costs$$

	Cost Per Acre Inch	Cost Per Acre	Annual Costs
Total Ownership Costs		$136.54	$21,847.19
Total Operating Costs	$8.87	$35.49	$5,678.21
Total Annual Costs		$172.03	$27,525.39

Figure 9: Total annual costs inside the irrigation budget

2.4 SUMMARY

Irrigation budgets help producers to estimate their annual ownership and operating costs of irrigation systems. This user's guide shows how these budgets are constructed and how to customize these budgets to reflect the irrigation costs of a specific farm. Producers can choose the irrigation management systems (checkbook, SMS plus, and app-based) and the crop (corn, cotton, peanut) in these irrigation budgets. Producers can also alter the default values in the budgets and customize them based upon their farm records.

CHAPTER 3 ECONOMIC ANALYSIS OF MODERN IRRIGATION SCHEDULING STRATEGIES FOR COTTON[2]

[2] Bhattarai, A. To be submitted to Agricultural Water Management

3.1 ABSTRACT

Cotton growers use irrigation as a risk management tool to mitigate the impact of weather on crop yield. Various irrigation scheduling methods were developed to guide cotton growers in their irrigation decisions. This research compares water use efficiency and profitability between dryland production (Control) with five different irrigation scheduling methods under conservation and conventional tillage practices over five (2013-2017) growing seasons. These irrigation scheduling methods include the UGA checkbook method (Checkbook), smart irrigation cotton app (Cotton App), UGA smart sensor array (UGA SSA), cotton water stress index (CWSI), and Irrigator Pro. The results showed that irrigation improved cotton productivity and profitability during dry years. However, for wet years, over-irrigation reduced cotton productivity and profitability, and growers need to consider adopting more advanced irrigation scheduling methods to improve water use efficiency and profitability. Results also showed that the Cotton App was the most economically efficient irrigation scheduling method for both tillage practices.

3.2 INTRODUCTION

Water security is under the constant pressure of population growth, urbanization, and agricultural advancements, and has become the major issue in the present world (Bogardi et al., 2012). By 2050, water scarcity is predicted to affect about 66% of the population (Wallace and Gregory, 2002). Agriculture, the major consumer of water (Rosengrant and Cai, 2001), will be largest impacted by and face the grave challenge of water scarcity. As water is a determining factor in agricultural production, producers use irrigation to minimize the production risks caused by the uncertainties in weather conditions.

Globally, farmers have been using different sources of irrigation. Besides water from rivers, lakes, and ponds, groundwater is one of the main sources, which contributes around 38% of total irrigated land (Siebert et al., 2010). Wells and pumps are used to retrieve the water from the underground. However, the rate of recharging capacity must be higher than the rate of pumping to maintain the natural level of groundwater. As the percentage of irrigated land is increasing, the increasing number of pumps and wells has escalated the rate of pumping from the aquifer. In some circumstances, the rate of pumping is higher than the rate of recharging capacity of the aquifer, and thus aquifer capacity can be permanently damaged, leading to decreased water quality, ground subsidence, and other problems. To ensure water security, today's world should focus on developing and adopting more efficient irrigation methods in the agricultural sector. Cotton is the most common fiber crop contributing about one-third of the total fiber production around the globe. The U.S. is the third-largest cotton producing country in the world, after China and India. In 2019, U.S. farmers planted 5.6 million ha of cotton (Quickstats, 2019a), with an overall economic impact of 6 billion dollars (Quickstats, 2019c). Georgia is the second-highest cotton-producing state in the U.S. behind Texas. Cotton can withstand water stress in most of its growing period except during the critical phases from flowering to boll maturation. Episodic drought during these critical phases can significantly lower the cotton yield (Snowden et al., 2014, Zonta et al., 2017). As the occurrence of rain varies from year to year, the application of irrigation is essential for minimizing risks associated with the yield variability. On average, around 50 % of the cotton field is irrigated in the U.S. (USDA, 2018).

The majority of the cotton growers use traditional irrigation scheduling methods such as visible stress of the plants, feeling of the soil, calendar-based method, or when the neighbor irrigate (USDA, 2018). These traditional scheduling methods do not consider the amount of water already present in the soil, which might result in either over or under irrigation. An excessive amount of water above the needs of the cotton crop can lead to excessive vegetative growth and fewer photosynthates for growing flowers and thus lower the yield potential (Grimes, 1994, Karam et al., 2006, Wanjura et al., 2002). Conversely, under irrigation, especially during the critical phases, can also be equally devastating for the cotton yield. Therefore, more efficient use of irrigation can conserve the water resource and also maintain the higher lint yield (DeLaune et al., 2020).

The knowledge of the right amounts and time to irrigate plays a key role in maintaining irrigation water use efficiency (Colaizzi et al., 2003). Several modern irrigation scheduling methods have been developed to resolve the imminent problem of reduced water resources (Awan et al., 2012, Liang et al., 2016, Pereira et al., 2007). These irrigation scheduling methods consider the soil moisture and the water needed by the crop based on its growing stages to estimate the irrigation time and amount to prevent over or under irrigation. By adopting these methods, it can significantly improve the irrigation water use efficiency, and help lessen the water scarcity problem in agricultural production. Various studies have been carried out to investigate the sustainability and efficiency of these irrigation scheduling methods (Miller et al., 2018, Vellidis, Liakos, Andreis, Perry, Porter, Barnes, Morgan, Fraisse, and Migliaccio, 2016). 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 (Epperson et al., 1993, Kranz et al., 1992, Lecina, 2016, Vatta et al., 2018). However, the economic impacts of modern irrigation scheduling strategies on cotton production have not been carried out.

The main objective of this study is to compare the economic efficiency of different irrigation scheduling methods under different tillage practices. Five different irrigation scheduling methods were developed at the University of Georgia (UGA) to reduce water usage, increase water use efficiency, and improve the yield and overall sustainability of the production system. These irrigation scheduling methods include the UGA checkbook method (Checkbook), smart irrigation cotton app (Cotton App), UGA smart sensor array (UGA SSA), cotton water stress index (CWSI), and Irrigator Pro. Two different types of UGA SSA methods were used in this study, UGA SSA with a constant threshold of 50 kPa (UGA SSA C), and UGA SSA with variable thresholds (UGA SSA V). In this research, these irrigation scheduling methods were compared with dryland control (Control) to identify the most profitable irrigation scheduling method for cotton producers. Results show that in the dry year, the Cotton App was the most economically efficient irrigation methods. However, in the wet years, rainfed conditions produced the highest yield and the highest net return than the irrigation scheduling methods, and among all the irrigation scheduling treatments, Cotton App is more profitable than the other irrigation scheduling methods.

3.3 MATERIAL AND METHODS

3.3.1 Irrigation Scheduling Methods

Most of the innovative irrigation scheduling methods are based on deficit irrigation, which was found to be more efficient than the full irrigation scheduling system (Grove and Oosthuizen, 2010). These methods schedule irrigation to lower the water stress caused by drought, reduce the amount of irrigation water used, and improve crop productivity. An excessive amount of water above the needs of the cotton crop can lead to excessive vegetative growth and fewer photosynthates for growing flowers and thus lower the yield potential (Grimes, 1994, Karam et al., 2006, Wanjura et al., 2002). Reduced irrigation during cotton growth stages like germination, seedling emergence, and squaring raised the irrigation water use efficiency and increased the cotton yield (Himanshu et al., 2019). Conversely, under irrigation, especially during the critical phases from flowering to boll maturation, can also be equally devastating for the cotton yield. For better cotton yield, the level of water limitation should be relatively mild rather than an extremely high level of water deficit (Pereira et al., 2009). Therefore, techniques that can efficiently provide the appropriate amount of water needed by the cotton plant are essential for increasing cotton production.

Five different irrigation scheduling techniques were investigated in this study to evaluate the economic efficiency of innovative irrigation scheduling methods. These methods include the UGA checkbook method (Checkbook), the smart irrigation cotton app (Cotton App), the UGA smart sensor array (UGA SSA), cotton water stress index (CWSI), and the Irrigator Pro.

The UGA checkbook method (Checkbook) is a calendar-based method developed by UGA Extension, which provides the weekly requirements of water for cotton. The method assumes that the cotton crop requires approximately 20 millimeters of water each week prior to flowering, and after the first bloom, the irrigation is applied according to the weekly water requirement listed in Table 4. Irrigation is eventually terminated at the first open boll stage. This method requires growers to record daily rainfall through rain gauzes and subtract the total weekly rainfall from the weekly water requirements to get the irrigation needed. However, this method does not take into account of the soil moisture, and, hence, it may result in over-irrigation.

Table 4. Cotton Checkbook Irrigation Scheduling Method recommendation by UGA Extension

Crop Stage	**Millimeters/Week**	**Millimeters/Day**
Week beginning at 1^{st} bloom	25.4	3.81
2^{nd} week after 1^{st} bloom	38.1	5.58
3^{rd} week after 1^{st} bloom	50.8	7.62
4^{th} week after 1^{st} bloom	50.8	7.62
5^{th} week after 1^{st} bloom	38.1	5.58
6^{th} week after 1^{st} bloom	38.1	5.58
7^{th} week and beyond	25.4	3.81

The Smart Irrigation Cotton App (Cotton App) is an interactive evapotranspiration (ET) based irrigation scheduling method using deficit irrigation (Vellidis, Liakos, Andreis, Perry, Porter, Barnes, Morgan, Fraisse, and Migliaccio, 2016). 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 smartphones for free. Using Cotton App, users need to input the information of the location, soil type, and irrigation type. Cotton App uses the meteorological data from the nearest weather station and estimates the amount of water to irrigate and time to irrigate (Vellidis, Liakos, Andreis, Perry, Porter, Barnes, Morgan, Fraisse, and Migliaccio, 2016).

University of Georgia Smart Sensor Array (UGA SSA) is a soil moisture sensor-based system, which schedules irrigation according to the soil moisture data measured (Liakos et al., 2017, Vellidis et al., 2013). Sensors are installed at different depths (0.2, 0.3, and 0.4 meters), which send hourly soil moisture data to the base station. The soil moisture data is uploaded to a server, which converts the data to volumetric water content and recommends the amount and time of irrigation water needed by the plant.

The cotton water stress index (CWSI) evaluates the plant's water stress level on the leaves using infrared sensors to monitor the average canopy temperatures (Chastain et al., 2016). CWSI is calculated by comparing the difference between the temperature of plant canopy and the air with respect to the difference between the temperature of plant canopy of non-transpiring crops and the air (Idso et al., 1981). Due to insufficient transpirational cooling, stressed leaves have a higher temperature than non-stressed leaves. Irrigation is provided after the stress is observed on the leaves (Jensen et al., 1990).

Irrigator Pro is another sensor-based scheduling method that estimates available soil water content. The soil water content is estimated from the soil water tension data collected from the sensors at two different depths (0.2 and 0.4 meters). Irrigation is applied after the soil water tension exceeds a specific threshold. To increase the accuracy in irrigation recommendations, a web-based version of Irrigator Pro is also available that can download soil moisture data from the UGA SSA system.

3.3.2 Experiment Description

Cotton irrigation field trials were conducted from 2013 to 2017 at the University of Georgia C.M. Stripling Irrigation Research Park in Camilla, Georgia (Latitude: 31.281632, Longitude: -84.294388). A complete randomized block split-plot experimental design was used in the field trial. Irrigation treatment was the whole-plot factor, while the cotton variety and tillage method were the split-plot factors. *Table 5* 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. To promote uniform stand establishment and active weed control programs, irrigation was applied to dryland production in the field trial. After that, no irrigation was applied to dryland production. Two different types of UGA SSA was evaluated, including the UGA SSA with the constant threshold of 50 kPa (UGA SSA C) and UGA SSA with the variable threshold (UGA SSA V). For the UGA SSA V, the threshold changes according to the growth stage of the crop, which is 50 kPa threshold before flowering and 40 kPa after flowering.

Table 5 Irrigation treatments for each year from 2013 to 2017.

Treatment	**2013**	**2014**	**2015**	**2016**	**2017**
1	Control	Control	Control	Control	Control
2	Checkbook	Checkbook	Checkbook	Checkbook	Checkbook
3	Cotton App	Cotton App	Cotton App	Cotton App	Cotton App
4	-	UGA SSA C	UGA SSA C	UGA SSA C	UGA SSA C
5	-	-	UGA SSA V	UGA SSA V	-
6	Irrigator Pro	-	-	-	-
7	-	-	-	-	Pro SSA
8	CWSI	-	-	-	-

Except for 2013, seeds of four commercially available cotton cultivars were sown at one seed per 0.3 m with 0.91 m inter-row spacing at a depth of 0.019 m. In 2013, a single variety of cotton was planted. *Table 6* lists the varieties of cotton planted for each year. The plot size was 15.2 m long × 1.8 m wide with 18.2 m alleys among the plots. Three replications were conducted for each irrigation, cultivar, and tillage treatment. There were 27 plots (5 Irrigation Treatments × 1 Cultivars × 2 Tillages × 3 Replicates, Control only in conservation tillage) for 2013, 84 plots (4 Irrigation Treatments × 4 Cultivars × 2 Tillages × 3 Replicates, Control only in conservation tillage) for 2014, and 108 plots (5 Irrigation Treatments × 4 Cultivars × 2 Tillages × 3 Replicates, Control only in conservation tillage) from 2015 to 2017. All other inputs, including fertilizers and pesticides, were kept constant for all plots. All the plots were irrigated with the lateral variable rate irrigation. The lateral variable rate irrigation categorized the plots into different irrigation management zones, which makes it possible to apply different irrigation application rates to different plots.

Table 6: Variety treatments in each year for both tillage practices.

Variety	2013	2014	2015	2016	2017
1	DP1252	DP1252	-	-	-
2	-	-	DP0912	-	-
3	-	-	-	DP1522	-
4	-	-	-	-	DP1555
5	-	FM1944	FM1944	FM1944	FM1944
6	-	PHY333	PHY333	PHY333	PHY333
7	-	PHY499	PHY499	PHY499	PHY499

Cotton from each plot was harvested with a two-row spindle cotton picker at the end of the season. Seed cotton weight was recorded on-site and transported to the University of

Georgia Micro Gin to obtain the gin turnout ratio and lint yield for each plot. Additionally, samples were sent to the classing office to obtain the HVI analysis of cotton fiber quality for each plot. The fiber quality of cotton was analyzed at different facilities. In 2014, gin samples were analyzed in the Fiber and Biopolymer Research Institute of Texas Tech University in Lubbock, Texas. For the rest of the years, samples were analyzed in the U.S. Department of Agriculture cotton program classing office Macon, GA. Depending on the fiber quality[3], producers can receive premiums or face discounts when they sell their cotton at the market place.

3.3.3 Irrigation Water Use Efficiency (IWUE)

The amount of irrigation and lint yield for each treatment were used to calculate the Irrigation Water Use Efficiency (IWUE). IWUE represents the additional amount of cotton produced for each unit of irrigation applied for a specific irrigation scheduling method ($treatment$) compared to the dryland control ($control$). IWUE can identify the irrigation scheduling method that can produce a higher yield per unit of water usage. Irrigation scheduling methods with a higher IWUE uses less water and can produce higher agricultural products (Fan et al., 2018).

$$IWUE = \frac{Yield_{treatment} - Yield_{control}}{Irrigation_{treatment} - Irrigation_{control}} \quad (\text{kg ha}^{-1}\ \text{mm}^{-1})$$

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[3] The base quality of upland cotton has the following characteristics: color grade 41, leaf grade 4, staple 34, micronaire 35-36 and 43-49, strength readings of 27.0-28.9 grams per tex, and length uniformity of 80.0-81.9%.

Where, $Yield_{treatment}$ is the lint yield from a specific irrigation scheduling method in kg ha^{-1}. $Yield_{control}$ is the lint yield from the dryland control in kg ha^{-1}. $Irrigation_{treatment}$ is the irrigation amount for the given irrigation scheduling method in mm. $Irrigation_{control}$ is the irrigation amount for the dryland control in mm.

3.3.4 Net Return

Economic analyses were conducted to investigate the economic efficiency among different irrigation scheduling methods. Data from the field trial were used to calculate the net return per hectare over irrigation, harvest, and ginning costs for each irrigation treatment (net return), which is used to identify the most economically efficient irrigation scheduling method. The gross revenue was first calculated for each replicate of the irrigation treatment, cultivar, and tillage systems in each production season.

$$Gross\ revenue = lint\ yield \times lint\ price + seed\ yield \times seed\ price$$

The cotton lint yield was obtained from field trials from 2014 to 2017 for each plot and each treatment after the ginning of seed cotton. The seed yield was estimated by using a conversion ratio of 1.412 units of seed per unit of lint from the Cotton Loan Calculator developed by Cotton Incorporated (Falconer and Reeves, 2017). The base quality market price of cotton lint and premium or discounts for the different fiber quality for each year was obtained from Cotton Price Statistics Annual Reports (USDA-AMS, 2014, 2015, 2016, 2017, 2018). The premium or discounts are adjusted with the base quality market price of the lint based on the fiber quality of each replicate. Cottonseed price was obtained from the USDA National Agricultural Statistics Service (NASS) for each year (USDA, 2013, 2014, 2015, 2016, 2017). According to USDA, AMS, the base quality market price was \$1.77 kg^{-1} in 2013, \$1.36 kg^{-1} in 2014, \$1.34 kg^{-1} in 2015, \$1.56 kg^{-1} in 2016, and \$1.67 kg^{-1} in 2017.

Total expenditure was estimated for the cost of irrigation, harvesting, and ginning cost of cotton production. Ginning costs and harvesting costs were calculated for each irrigation treatment. Harvest costs and ginning costs were assumed to be proportional to yields (Falconer and Reeves, 2017). Ginning costs (per pound of cotton lint) were derived from the University of Georgia Cotton Enterprise Budget for each year (Shurley and Smith, 2013, 2014, 2015, 2016, 2017). Harvesting costs (per pound of seed cotton) come from Cotton Incorporated Cotton Loan Calculators (Falconer and Reeves, 2017). The total expenditure was calculated as,

$$Total\ expenditure = cost\ of\ irrigation + harvesting\ cost + ginning\ cost$$

UGA Extension Irrigation Budgets (Bhattarai et al., 2020) were used to estimate the costs of irrigation, which include ownership and operating costs. 160 acres electricity operated center pivot system irrigation budget was used in this analysis. Ownership costs are the annual fixed costs associated with alternative irrigation systems, which consist of the depreciation costs, intermediate interest costs, tax and insurance costs. Operating costs, also called variable costs, changes with the amount of water usage. Operating costs include fuel or electricity costs, repairs and maintenance costs, and labor and management costs. Based on the irrigated amount, the irrigation budgets estimate the costs for each irrigation scheduling method within each year. The cost of irrigation for the dryland control was assumed to be zero in our analysis. This assumption is to follow the production practice and cost schedule of cotton growers for dryland production. Finally, the net return for each irrigation treatment was obtained from the difference between gross revenue and total expenditures as follows,

$$Net\ return = gross\ revenue - total\ expenditure$$

RStudio Version 1.2.5001 was used to conduct the Analyze of Variance (ANOVA) for net returns of each irrigation scheduling system. Tukey tests were done to find the significant differences in mean values among the irrigation scheduling systems at a 5% significant level. These tests were conducted within the same tillage practice and but not between the tillage practices for the irrigation scheduling methods.

3.4 RESULTS AND DISCUSSIONS

3.4.1 Precipitation and Irrigation

For each experimental year, the rainfall amounts were different. Due to El Nino phenomenon, 2013 and 2015 had higher precipitation of 696 and 575 mm respectively (Nuccitelli, 2014, Sumner, 2016). 2016 (649 mm) and 2017 (616 mm) also received higher rainfall. In 2014, however, lack of tropical systems coming up from the Gulf of Mexico (Bekham and Thompson, 2014) resulted in lesser precipitation of about 285 mm. The year 2013, 2015, 2016, and 2017 were considered wet years as the annual precipitation in these years exceeded the total optimum amount of water required for cotton production (457 mm) throughout its growing period till harvest (Bednarz et al., 2002). Since the year 2014 received 285 mm of rainfall, it was considered a dry year. Similarly, different irrigation scheduling treatments received different irrigation amount across the years. This variation determined the irrigation costs of each treatment. Table 7 shows the rainfall, irrigation amount, and irrigation cost of each year for conservation tillage and conventional tillage, respectively. 160 acres electric engine center pivot irrigation budgets (160 E) was used to estimate the ownership and operating costs of each irrigation schedules across the years. The cost of irrigation was assumed to be zero for the Control. Irrigation costs were found to be higher for checkbook method.

Table 7: Rainfall, irrigation, and cost of irrigation for cotton grown near Camillia, GA during the 2013 to 2017 growing season for conservation and conventional tillage.

			Conservation Tillage		Conventional Tillage	
Year	Rainfall	Treatment	Irrigation	Irrigation Cost	Irrigation	Irrigation Cost
	-- mm --		-- mm --	$ Ha^{-1}	-- mm --	$ Ha^{-1}
2013	696	Control	38	0	-	-
		Checkbook	323	561	310	554
		Cotton App	76	408	76	408
		Irrigator Pro	56	388	56	403
		CWSI	114	440	56	403
2014	285	Control	97	0	-	-
		Checkbook	387	603	388	603
		Cotton App	231	504	231	504
		UGA SSA C	372	601	315	566
2015	574	Control	13	0	-	-
		Checkbook	165	462	165	462
		Cotton App	127	440	137	449
		UGA SSA C	137	447	89	427
		UGA SSA V	99	420	203	492
2016	650	Control	19	0	-	-
		Checkbook	203	487	203	487
		Cotton App	133	443	133	443
		UGA SSA C	83	421	57	403
		UGA SSA V	70	413	64	408
2017	617	Control	13	0	-	-
		Checkbook	241	512	241	512
		Cotton App	114	430	114	430
		UGA SSA C	45	403	102	408
		Pro SSA	55	396	64	433

3.4.2 Lint Yield

Table 8 shows the result for lint yield (kg ha^{-1}) for each year under both conservation and conventional tillage practices. In 2013, there was no significant difference in the lint yield between the irrigation schedules for conservation and conventional tillage practices. Irrigator Pro produced highest with 1678 kg ha^{-1} of lint, and checkbook method produced the lowest with 1513 kg ha^{-1} of lint for conservation tillage. Similarly, CWSI yielded highest lint, 1511 kg ha^{-1} for conventional tillage. However, in dry year 2014, there was significant difference in lint yield between Control and all other irrigation schedules, Checkbook, Cotton App, and UGA SSA C for conservation tillage. Cotton App and UGA SSA C also showed significant difference in the lint yield. The highest lint yield was resulted from the cotton app, 2040 kg ha^{-1}. In contrast, there was no significant difference among the irrigation schedules for conventional tillage. In 2015, significant difference was observed between Checkbook and UGA SSA C, and also between Checkbook and Control. In this year, highest lint yield was obtained from Control. Conventional tillage did not show any significant difference among the irrigation treatments for this year as well. Similarly, in 2016, significant difference in lint yield was found between Checkbook and Control. In this year as well Control produced the highest lint yield of 1371 kg ha^{-1}. Unlike other year, statistical difference was observed for conventional tillage in 2016. Checkbook produced significantly lower lint yield than all other irrigation schedules. This result can be a strong evidence for suggesting the modern irrigation scheduling methods being better than the calendar based method. Finally, in 2017, lint yield was significantly lower for checkbook than other irrigation scheduling methods including the Control. For conventional tillage, however, there were no significant difference among the irrigation schedules. In all wet years, lint yield was found to be lowest for checkbook. Similarly, lint yield was highest in dryland control except for 2013. This suggests that when there is enough rainfall in the growing season farmers can choose not to irrigate their field. However, farmer can get more lint yield, if they opt to irrigate their field using modern irrigation schedules rather than the calendar based checkbook method.

Table 8. Summary statistics of lint yield of alternative irrigation scheduling methods from 2013 to 2017 under conservation tillage and conventional tillage.

		Conservation Tillage				Conventional Tillage			
Year	Treatment	Mean	S.D	Min	Max	Mean	S.D	Min	Max
		---------$Kg\ Ha^{-1}$---------				---------$Kg\ Ha^{-1}$---------			
2013	Control	1659[a]	152	1519	1820	-	-	-	-
	Checkbook	1513[a]	176	1320	1666	1290[a]	131	1146	1402
	Cotton App	1666[a]	222	1417	1845	1413[a]	157	1305	1594
	Irrigator Pro	1678[a]	197	1551	1904	1359[a]	83	1280	1603
	CWSI	1618[a]	449	1263	2122	1511[a]	152	1336	1445
2014	Control	1243[c]	317	828	1742	-	-	-	-
	Checkbook	1931[ab]	474	1318	3019	1989[a]	416	1320	2847
	Cotton App	2040[b]	454	1466	2888	2112[a]	258	1804	2609
	UGA SSA C	1652[a]	261	1075	2062	2003[a]	246	1594	2346
2015	Control	1832[b]	212	1461	2099	-	-	-	-
	Checkbook	1656[a]	187	1258	1978	1657[a]	244	1358	1995
	Cotton App	1711[ab]	170	1470	2055	1794[a]	210	1455	2083
	UGA SSA C	1822[ab]	155	1661	2078	1727[a]	257	1321	2126
	UGA SSA V	1738[b]	162	1522	2018	1712[a]	188	1516	2158
2016	Control	1371[b]	127	1208	1599	-	-	-	-
	Checkbook	1017[a]	142	835	1406	812[a]	233	586	1176
	Cotton App	1196[ab]	153	938	1417	1098[b]	277	781	1589
	UGA SSA C	1237[ab]	175	886	1576	1381[b]	106	1139	1718
	UGA SSA V	1274[ab]	68	1111	1366	1316[b]	89	1125	1566
2017	Control	1471[b]	73	1327	1760	-	-	-	-
	Checkbook	1251[a]	87	1047	1629	1251[a]	161	899	1487
	Cotton App	1484[b]	97	1182	1642	1484[a]	112	1159	1807
	UGA SSA C	1423[b]	52	1321	1611	1388[a]	149	886	1556
	Pro SSA	1490[b]	106	1251	1628	1257[a]	240	1104	1861

Within a given year, means for different irrigation treatment followed by the same letter are not significantly different from each other at $P<0.05$.

3.4.3 IWUE

Figure 10 shows the result for IWUE from 2013 to 2017. Positive IWUE value was observed in 2014, which is a relative dry year. The results implied that irrigation could improve yield and productivity when there is less preexisting moisture in the field during dry years. Our results also supports the findings from previous research that higher cotton yield was achieved from the irrigated condition than the dry land regime during the dry years (Sorensen and Lamb, 2019). The IWUE value for the cotton app was 5.9 and 6.4 kg ha^{-1} mm^{-1} for conservation and conventional tillage practices, respectively. This suggests that the cotton plant is producing more if they are irrigated by using a deficit irrigation-based cotton app. This coincides with previous studies of deficit irrigation having higher water use efficiency (Fan et al., 2018, Jalota et al., 2008, Liang et al., 2016, Miller et al., 2018, Ünlü et al., 2011).

In wet years, most of the irrigation scheduling methods resulted in the negative IWUE. This implies that over irrigation during wet years wasted water and reduced yield. Vellidis et al. (2016) also 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.

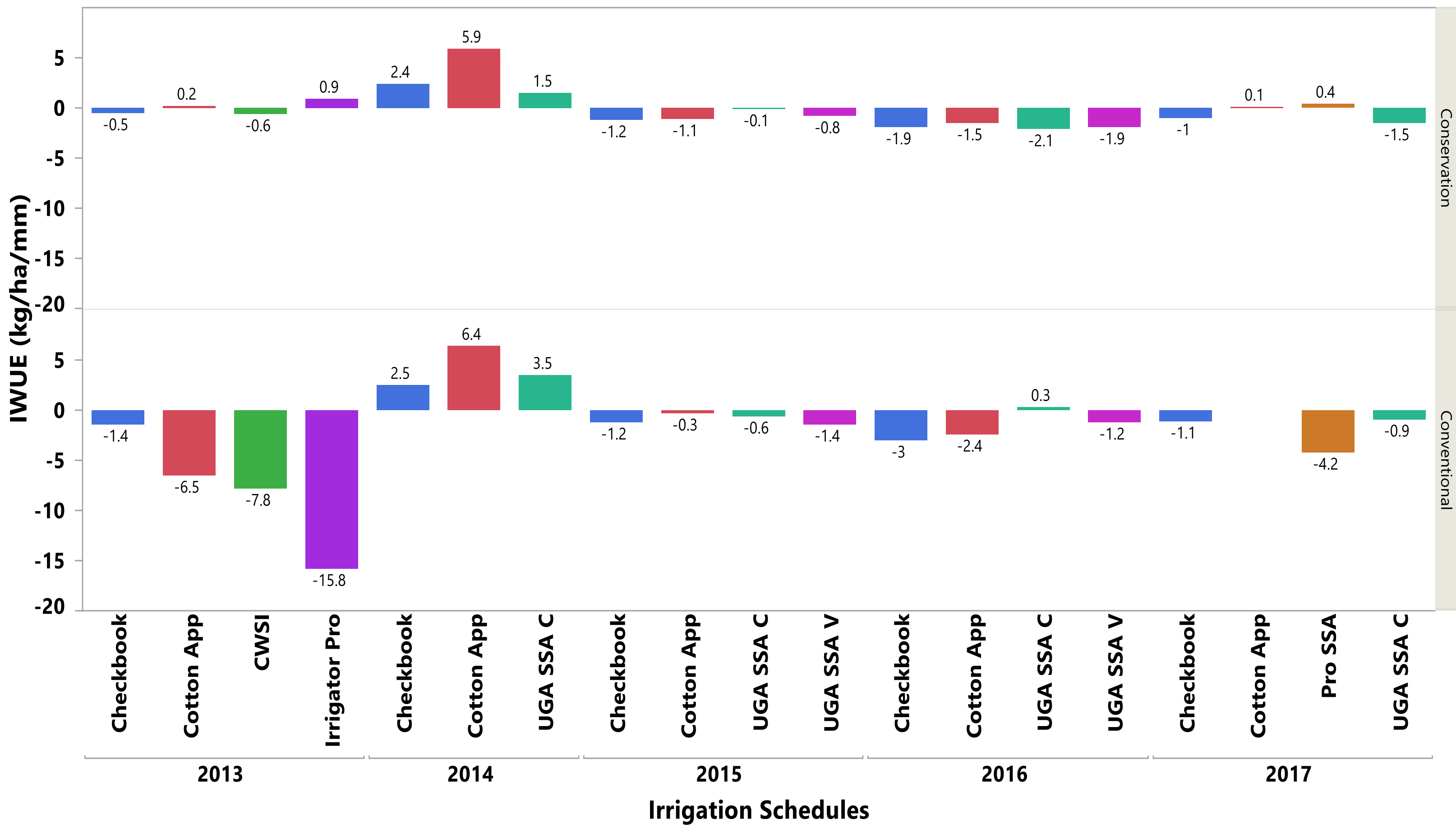

Figure 10: IWUE for each irrigation scheduling treatment under conservation and conventional practices.

Net Return

Figure 11 displays the result of the net return. For 2013, there was no significant difference in net returns among different irrigation scheduling methods within the tillage practices. For conservation tillage, the highest net return is observed in the Control, 3199 $\$ ha^{-1}$, and lowest in the Checkbook with $2027 per hectare. For conventional tillage, the highest net return is for the CWSI, 2466 $\$ ha^{-1}$, and lowest for the Checkbook, 1905 $\$ ha^{-1}$. In 2015 as well, no any significance differences were observed in both practices. Highest net return was obtained in the Control, 2579 $\$ ha^{-1}$, for conservation practice, and Cotton App, 2084 $\$ ha^{-1}$, for conventional tillage.

For 2016, the calendar-based checkbook method resulted in a lower average net return than the modern irrigation scheduling method like UGA SSA V. Similarly, in 2017, the modern irrigation schedules like Cotton App, UGA SSA C, and UGA SSA V gave significantly higher net return than the Checkbook. Results also indicate that using modern irrigation scheduling methods is better than the calendar based checkbook method during wet years. In both years, Dry resulted significantly higher net return than other irrigation scheduling methods. This reveals that if there is enough precipitation during the growing season, additional irrigation is detrimental to the yield and profitability. For conventional tillage, there was significant difference between the net returns of the Checkbook, and all other irrigation schedules including the Control in 2016. No statistical significance was observed in 2017.

The net return for dry year in 2014 shows the significant difference between, the Cotton App and the Control, and the Cotton App and UGA SSA C for conservation tillage. However, for conventional tillage, there were no significant differences among the scheduling systems. For both tillage practices, the Cotton App yielded the highest net return, and UGA SSA C resulted the lowest. This shows that in a dry year, the Cotton App is an economically efficient irrigation scheduling method.

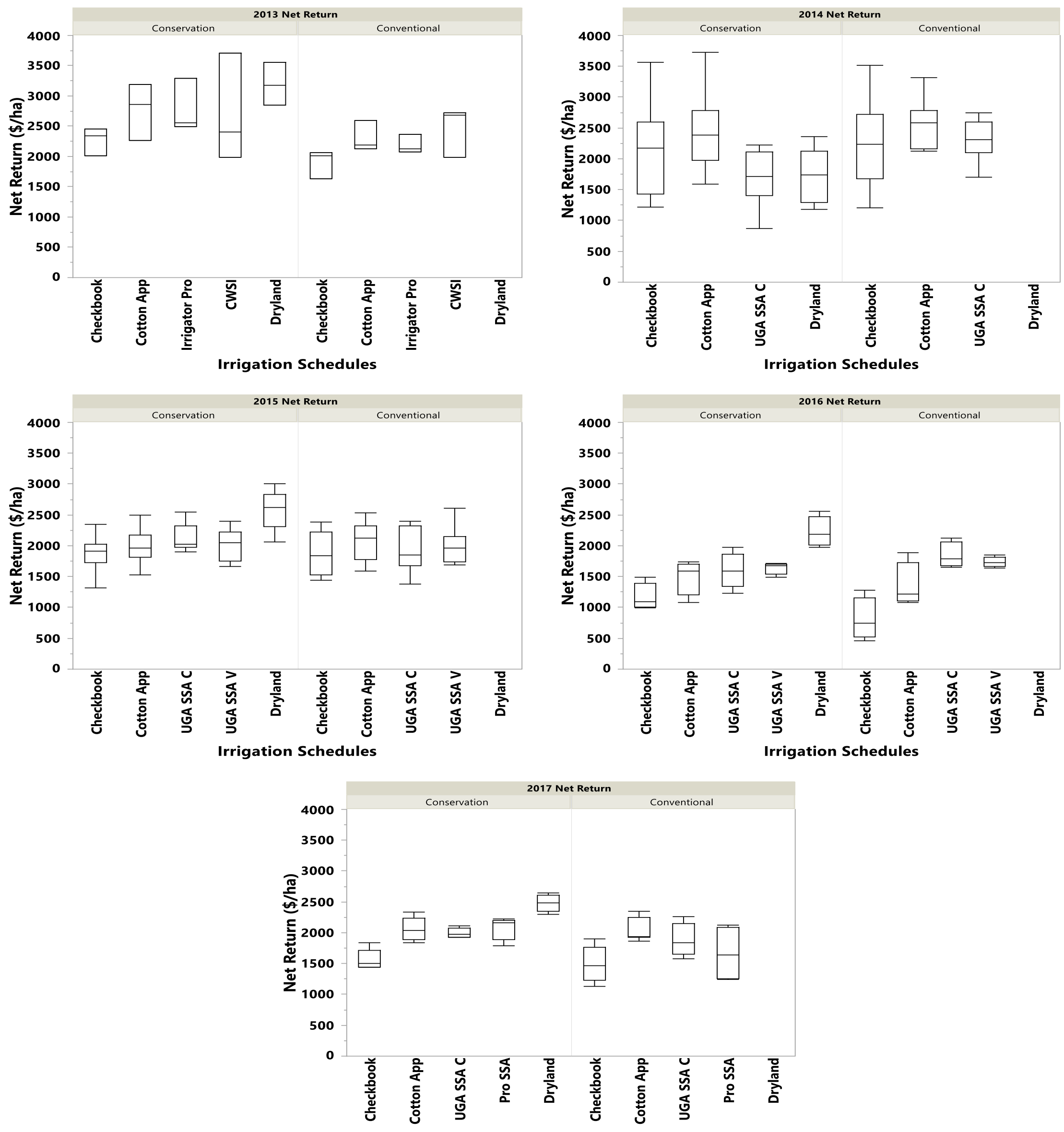

Figure 11: Net return ($ Ha^{-1}) of cotton production for different irrigation schedules across the years under conservation and conventional tillage practices.

3.5 SENSITIVITY ANALYSIS

This analysis enlightens the impact of different irrigation budgets on the net return of the cotton production. There are four different types of UGA extension irrigation budgets, 160 acres electric (160 E) operated center pivot irrigation budget, 160 acres diesel (160 D) operated center pivot irrigation budget, 65 acres electric (65 E) operated center pivot irrigation budget, and 65 acres diesel (65 D) operated irrigation budget, used for this analysis.

3.5.1 Impact on Irrigation Costs

In Table 9, irrigation costs using all four types of irrigation budgets are represented. Among four irrigation budgets, 65 D resulted in higher ownership and operating costs followed by 65 E, 160 D, and finally, 160 E. This can be due to two major factor, first, the size of the pivot, and second, energy used for the operation. The bigger sized pivot covers larger area for irrigation and tends to have a lesser cost of owning and operating, per hectare. Similarly, the pivot operated through electricity is cheaper than the diesel operated which have a higher fuel and gearhead system cost.

3.5.2 Impact on Net Return

The 160 D irrigation budget resulted in lower net return (Table 10) than the 160 E, because of the higher irrigation costs. When 160 D was used for estimating the irrigation costs, in 2013, no significant difference was found among the irrigation schedules for conservation tillage. However, the net return of CWSI was significantly higher than the Checkbook in conventional tillage. In 2014, unlike 160 E, there was no significant difference between the Cotton App and the Control. However, the Cotton App yielded significantly higher net return than the UGA SSA C. No significant difference was seen across irrigation schedules in conventional tillage.

Table 9: Irrigation costs ($/ha) using irrigation budgets.

		Conservation Tillage			Conventional Tillage		
Year	Treatment	160 D	65 E	65 D	160 D	65 E	65 D
		--------$ Ha^{-1}--------			--------$ Ha^{-1}--------		
2013	Checkbook	804	981	1216	789	971	1201
	Cotton App	500	796	942	500	796	942
	Irrigator Pro	487	798	934	487	798	934
	CWSI	559	843	1001	487	798	934
2014	Checkbook	883	1030	1288	883	1030	1288
	Cotton App	692	912	1115	692	912	1115
	UGA SSA C	875	1035	1285	806	993	1223
2015	Checkbook	611	862	1040	611	862	1040
	Cotton App	564	833	998	579	843	1013
	UGA SSA C	574	852	1014	535	828	979
	UGA SSA V	519	817	964	660	905	1091
2016	Checkbook	658	892	1082	658	892	1082
	Cotton App	571	838	1006	571	838	1006
	UGA SSA C	519	818	963	487	798	936
	UGA SSA V	504	808	951	497	803	944
2017	Checkbook	705	919	1124	705	919	1124
	Cotton App	547	823	984	547	823	984
	UGA SSA C	497	798	934	497	803	944
	Pro SSA	541	791	921	541	833	986

Experimental year 2015, 2016, and 2017 resulted significantly higher net return from the Control, than any other irrigation schedules. In 2016 and 2017, the Checkbook resulted in significantly lower net return than UGA SSA C, UGA SSA V, Cotton App, and Pro SSA. For conventional tillage, statistically higher net return was resulted from the Cotton App than the Checkbook in 2016 and 2017. This further support the fact that, it better to choose modern irrigation scheduling methods than conventional.

Table 10: Net returns (\$/ha) using irrigation budgets.

		Conservation Tillage			Conventional Tillage		
Year	Treatment	160 D	65 E	65 D	160 D	65 E	65 D
		--------\$ Ha^{-1}--------			--------\$ Ha^{-1}--------		
2013	Control	3199^{a}	3199^{a}	3199^{b}	-	-	-
	Checkbook	2027^{a}	1849^{a}	1614^{a}	1670^{a}	1487^{a}	1258^{a}
	Cotton App	2681^{a}	2385^{a}	2239^{ab}	2112^{ab}	1916^{a}	1770^{ab}
	Irrigator Pro	2700^{a}	2388^{a}	2253^{ab}	2106^{ab}	1795^{a}	1659^{ab}
	CWSI	2578^{a}	2294^{a}	2136^{ab}	2382^{b}	2070^{a}	1934^{b}
2014	Control	1723^{ab}	1723^{ab}	1723^{ab}	-	-	-
	Checkbook	1855^{ab}	1706^{ab}	1450^{a}	1958^{a}	1810^{a}	1553^{a}
	Cotton App	2037^{a}	2037^{a}	1834^{a}	2364^{a}	2144^{a}	1942^{a}
	UGA SSA C	1279^{b}	1279^{b}	1028^{b}	2062^{a}	1874^{a}	1644^{a}
2015	Control	2579^{b}	2579^{b}	2579^{b}	-	-	-
	Checkbook	1732^{a}	1481^{a}	1303^{a}	1715^{a}	1463^{a}	1284^{a}
	Cotton App	1850^{a}	1582^{a}	1416^{ac}	1954^{a}	1690^{a}	1519^{a}
	UGA SSA C	2045^{a}	1747^{a}	1599^{c}	1763^{a}	1519^{a}	1332^{a}
	UGA SSA V	1889^{a}	1611^{a}	1449^{ac}	1874^{a}	1582^{a}	1431^{a}
2016	Control	2226^{c}	2226^{c}	2226^{c}	-	-	-
	Checkbook	997^{a}	762^{a}	572^{a}	639^{a}	404^{b}	214^{b}
	Cotton App	1373^{ab}	1107^{ab}	939^{ab}	1223^{b}	956^{a}	788^{a}
	UGA SSA C	1500^{b}	1201^{ab}	1054^{b}	1761^{c}	1450^{a}	1312^{a}
	UGA SSA V	1550^{b}	1246^{b}	1103^{b}	1646^{bc}	1339^{a}	1198^{a}
2017	Control	2475^{c}	2475^{c}	2475^{c}	-	-	-
	Checkbook	1368^{a}	1153^{a}	948^{a}	1296^{a}	1081^{a}	876^{a}
	Cotton App	1942^{b}	1665^{b}	1504^{b}	1915^{b}	1638^{a}	1478^{b}
	UGA SSA C	1941^{b}	1596^{b}	1465^{b}	1774^{ab}	1483^{a}	1330^{ab}
	Pro SSA	2003^{b}	1689^{b}	1553^{b}	1578^{ab}	1272^{a}	1131^{ab}

Within a given year, means for different irrigation treatment followed by the same letter are not significantly different from each other at $P<0.05$.

65 E irrigation budget, followed by 65 D budget (Table 10), gave even lower net return. This suggested that, as the size of the pivot decreases the irrigation cost per hectare increases.

3.6 CONCLUSIONS

This research compares five different irrigation scheduling methods by cotton yield, irrigation water use efficiency, and profitability. Lint yield was found to be higher for modern irrigation scheduling methods like cotton app, UGA SSA, and CWSI, than conventional checkbook method. In dry year, cotton app yielded significantly higher lint than UGA SSA. The IWUE was mostly negative for wet years inferring that when there is enough rainfall in the season the growers can opt out from the irrigation. But in dry year, cotton app was found to have very high IWUE than other scheduling methods. Economic analysis showed that in dry years, irrigation increased yield and profitability. The average net return from the cotton app was higher than UGA SSA and dryland 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. The cotton app was found to be an economically efficient irrigation scheduling method, and the use of this advanced irrigation scheduling tool can increase the farmer's profitability and water use efficiency.

All these results revealed that the choice of modern irrigation scheduling methods like the Cotton App, and UGA SSA could help cotton growers in increasing yield and profitability over the calendar based checkbook methods. The cotton yield and profitability were greatly affected by climatic factors such as rainfall. Higher precipitation in the growing season accompanied by the irrigation hurt the yield and profitability. However, significantly higher profits were obtained when the field was irrigated during the dry year. By adopting these methods, farmers can maximize the yield and net return while significantly reducing irrigation water usage, which ultimately can lead to solve the problem of water scarcity.

CHAPTER 4 ECONOMIC RISK ANALYSIS OF MODERN IRRIGATION SCHEDULING METHODS ON COTTON PRODUCTION IN GEORGIA[4]

[4] Bhattarai, A. To be submitted to Agricultural Systems

4.1 ABSTRACT

Modern irrigation scheduling methods have been proven to increase agricultural productivity and water use efficiency. But the adoption of these methods depends upon the risk preference of individual growers. We investigated the profitability and risks associated with alternative irrigation scheduling methods for cotton production under conservation tillage in Georgia. Three irrigation scheduling methods were compared, a calendar-based UGA checkbook method (Checkbook), a smart irrigation cotton app method (Cotton App), and dryland control (Control). Using data from a five-year field experiment (2013 - 2017), the net returns to all costs, excluding irrigation cost and harvest cost per hectare (net return) for each irrigation scheduling method were estimated. The net return distributions were then ranked using stochastic efficiency with respect to a function (SERF) method based on the risk aversion levels of cotton growers. Results show that certainty equivalents (CE) value for the Control was highest across all risk aversion levels. The utility weighted risk-premiums for the Cotton App range from -$108 to -$147 per ha compared with the Control, and $299 to $311 per ha compared with the Checkbook.

4.2 INTRODUCTION

The rapid growth of the world's population calls for more efficient usage of scarce natural resources in food and fiber production. Sustainability emerges as a solution to this grave problem, which can help in rational utilization of available resources, maintain a high standard of life and, at the same time, protect the environment and ecological system (Dresner, 2008, Gupta et al., 2012). Water, as one of the critical components of agricultural production, also faces its challenges as a scarce natural resource. More efficient use of water is required to ensure sustainability.

Cotton, which is the primary fiber producing crop, accounts for approximately 25% of total textile fibers (ERS, 2017b). United States is the largest producer in the world, behind China and India, and also the leading exporter of cotton globally (ERS, 2017a). 4.4 million metric tons of cotton were produced in the United States (Quickstats, 2019b) with a total economic impact of 6 billion dollars (Quickstats, 2019c). Georgia is the second-largest cotton-producing state in the United States, after Texas. Even though cotton is a relatively drought-tolerant crop, episodic drought during flowering and boll formation can result in significant yield loss (Zahoor et al., 2017). As the occurrence of rainfall varies from year to year, the application of irrigation during these critical phases can minimize the risk associated with yield variability. The knowledge of the amounts and the time to irrigate plays a key role in maintaining the water use efficiency (Colaizzi et al., 2003).

Modern irrigation scheduling methods are developed to reduce water usage, increase productivity and profitability, and maintain agricultural sustainability, which can aid in mending the water scarcity problem for future generations. These precision irrigation methods provide guidance of the time and the amount of water needed by the plants (Nagaz et al., 2007), which is critical to increase yield potential, improve water use efficiency, and reduce the cost of irrigation. However, only 23% of the growers in the United States adopt modern irrigation scheduling systems in their production (USDA, 2018). The majority of cotton growers irrigate their field after observing the visible stress in the plants, feeling of the soil, following the calendar schedule, or when their neighbor irrigates (USDA, 2018). However, these methods might result in yield reduction, water wastes, and thus reducing water use efficiency. The reason behind such a low adoption rate of modern irrigation scheduling methods can be the lack of knowledge about the value of risk associated with the new technology among the growers. An increase in the adoption of precision irrigation scheduling systems can be vital for more efficient use of irrigation water and maintain the economic and environmental sustainability.

Various economic researches have been conducted to investigate the efficiency of alternative irrigation scheduling methods in terms of productivity, profitability, and sustainability. Economic analysis of the irrigation scheduling systems for corn production revealed that advanced irrigation scheduling systems could decrease energy and water usage while improving profitability (Epperson et al., 1993, Kranz et al., 1992, Lecina, 2016, Vatta et al., 2018). Similarly, the irrigation schedules based on soil matric potential resulted in a higher yield of corn, with almost half less water used (Steele et al., 1994). The tensiometer-based method was found to be economically efficient, which could save water as well as improve potato yield (Shae et al., 1999). Singh et al. (2018) discovered that reduced irrigation resulted in a significantly higher net return in sugarcane. The irrigation scheduling method using deficit irrigation was proved to be a good alternative strategy increasing lint yield, water use efficiency, and profitability for cotton production in Texas Rolling Plains (Attia et al., 2016). However, the willingness of adoption of modern irrigation scheduling methods not only depends upon the economic profitability associated but also relies on the risks in income volatility with the new technology.

Risk analysis using Stochastic efficiency with respect to function (SERF) has been widely adopted in evaluating alternative farming practices (Fan et al., 2018, Liu et al., 2017, Liu et al., 2018, Wibowo et al., 2016, Williams et al., 2014). SERF method models risk attitudes and estimates the amount that the producers are willing to pay to switch from their existing farming practices to the new alternative (Adusumilli et al., 2020). Grove et al. (2006) used the SERF method to find water-conserving irrigation schedules for wheat and maize. They concluded that irrigation schedules based on deficit irrigation resulted in higher production, and risk-averse growers were more willing to adopt deficit irrigation scheduling methods for maize. However, economic research regarding the risk associated with the adoption of alternative irrigation schedules has not yet been carried out in cotton production.

Several irrigation scheduling methods have been developed at the University of Georgia, including the University of Georgia Checkbook method (Checkbook) and the Smart Irrigation Cotton App (Cotton App). Cotton irrigation field trials were conducted from 2013 to 2017 at Camilla, Georgia, to evaluate the efficiency of these modern irrigation scheduling methods. Using the data from the field trials, this study estimates the economic profitability of alternative irrigation scheduling methods developed at the University of Georgia and identifies the most economically efficient method. More specifically, this research investigates the economic benefits of adopting modern irrigation scheduling systems by considering the risk preference of individual producers. Stochastic efficiency with respect to function (SERF) was used to investigate the risk preference by cotton growers for alternative irrigation scheduling methods.

4.3 MATERIALS AND METHODS

4.3.1 Irrigation scheduling Methods

Beside increasing the farm profitability, irrigation can play major role in increasing the market value of the cotton (Ziolkowska, 2018) and can be a risk management strategy against the lower cotton yield (Senft, 1992). However, precision in irrigation application is needed for maintaining the stability in the yield which can be achieved with the help of modern irrigation scheduling techniques. A deficit irrigation scheduling system out performed full irrigation scheduling system in yield and water use efficiency (Grove and Oosthuizen, 2010). Pereira et al. (2009) concluded that relatively mild deficit irrigation in cotton saved water and resulted in higher production. Moreover, the ET-based irrigation scheduling method could significantly reduce the irrigation water use for cotton (Hunsaker et al., 2015). The reason is that over-irrigation can lead to production reduction, which is caused by more vegetative growth of the plants and fewer photosynthates availability for the growing flowers (Grimes, 1994). 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). Farmers might be unaware on the information about the economic profitability and risks associated with the new alternative techniques. Therefore, avoiding the alternative method and using the existing irrigation scheduling method seems to be better option for risk averse farmers.

This research compares the risk and economic returns of University of Georgia Checkbook method (Checkbook) and the Smart Irrigation Cotton App (Cotton App) with dryland production (Control). The checkbook method is most common calendar-based irrigation scheduling methods among the cotton growers in Georgia. It is based on water balance in the soil that uses soil moisture deficit to find out the appropriate time to irrigate (Lundstrom and Stegman, 1988). Water balance is maintained by figuring out the amount of water required by crop during its growing period, at the same time considering the weather variation such as rainfall. The UGA Extension has recommended weekly water requirements for cotton after the first bloom, and is portrayed in the Figure 12. Daily, and eventually weekly effective rainfall amount is measured with the help of rain gauges. The difference between weekly cotton water requirement and weekly effective rainfall gives the amount of water to be irrigated in the field. The major drawback of this method is to not consider the already available moisture in the soil. This can result in excessive irrigation eventually hurting the yield.

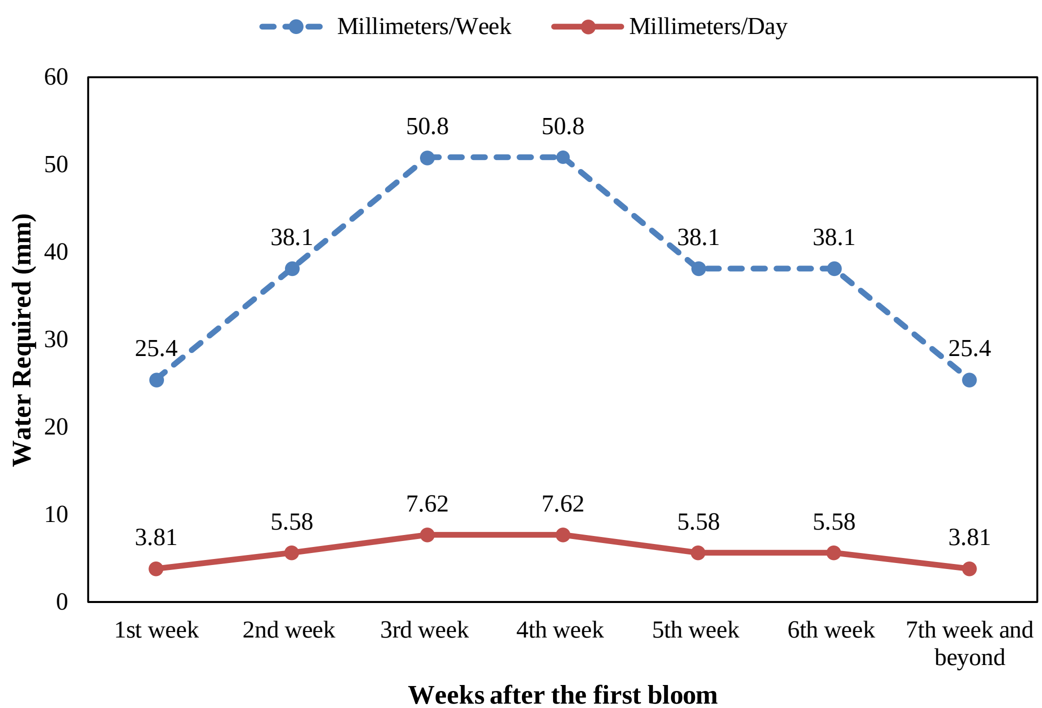

Figure 12: Cotton Checkbook Irrigation Scheduling Method recommendation by UGA Extension

As deficit irrigation can be a good technique to lower the water usage in the field (Costa et al., 2007, Fereres and Soriano, 2007), the Cotton App is one of the irrigation scheduling method grounded on deficit irrigation (Vellidis, Liakos, Andreis, Perry, Porter, Barnes, Morgan, Fraisse, and Migliaccio, 2016). It works on the principle of interactive evapotranspiration (ET) that uses real time weather and soil moisture data. Cotton App can be downloaded on the smartphones and users can input the information of location of their field, type of the soil, and irrigation type to get the amount of water to irrigate and time to irrigate (Vellidis, Liakos, Andreis, Perry, Porter, Barnes, Morgan, Fraisse, Migliaccio, et al., 2016). In order to find water deficit value, the app uses meteorological data from the nearest weather station, crop coefficient, crop phenology, soil parameters, and irrigation application. Unlike checkbook, this method considers the already available moisture in the soil and give the precise amount to be irrigated.

4.3.2 Experimental design

This research utilizes five years of field experiment data for cotton production from 2013 to 2017 at C.M. Stripling Irrigation Research Park located in Camilla, Georgia (Latitude: 31.281632, Longitude: -84.294388). The experimental design used in this research was a complete randomized block split-plot where irrigation treatments were the whole-plot factor, and tillage practices, the split-plot factors. However, risk efficiencies were estimated only for conservation tillage practice across three irrigation treatments, the Checkbook, the Cotton App, and the Dryland (control). Irrigation was provided to the control plots during the preparation of the field for promoting germination and activating weed control programs. There were three replications for each irrigation, and cultivar. Single variety, DP1252, was used in 2013. But for other years four different varieties were used. In 2014 varieties like DP1252, FM1944, PHY333, PHY499, in 2015, DP0912, FM1944, PHY333, PHY499 were used, in 2016, DP1522, FM1944, PHY333, PHY499, and in 2017, DP1555, FM1944, PHY333, and PHY499 were planted. Table 11 shows the number of plots across the year.

Table 11: Total number of plots across the irrigation treatments in Camilla, Georgia.

Year	Irrigation Treatments	Cultivars	Replicates	Tillage	Number of Plots
2013	3	1	3	1	9
2014	3	4	3	1	36
2015	3	4	3	1	36
2016	3	4	3	1	36
2017	3	4	3	1	36

Each plot was 15.2m long and1.8 m wide. Cotton seeds were planted in each plot with a spacing of 0.3m×0.91m at a depth of 0.019m. Plots were categorized into different irrigation management zones based upon the irrigation application rate. Other inputs, like fertilizers and pesticides, were kept constant for all plots. Lateral variable rate irrigation was used for irrigating the plots except for dryland control.

After cotton got matured, each plot was harvested with two-row spindle cotton picker, and seed cotton weight were obtained on-site. The harvested cotton was transported to UGA Micro Gin, and gin turnout ratio and lint yield were calculated for each plot. The USDA Agricultural Marketing Service (AMS) provides standard procedures to classify the quality of cotton based on physical attributes (color, staple length, leaf, extraneous matter, micronaire, length uniformity, and strength) of raw cotton fiber. The base quality of upland cotton has the following characteristics: color grade 41, leaf grade 4, staple 34, micronaire 35-36 and 43-49, strength readings of 27.0-28.9 grams per tex, and length uniformity of 80.0-81.9%. Depending on differences in the fiber quality from the base quality, producers can receive premiums or face discounts when they sell their cotton at the market place. The fiber quality of the cotton was analyzed at different facilities for USDA standard HVI tests. Except for 2014, whose gin samples were analyzed in the Fiber and Biopolymer Research Institute of Texas Tech University in Lubbock, Texas, for rest of the years, samples were analyzed in USDA cotton program classing office Macon, GA.

4.3.3 Net Return

For addressing the first objective of this project, economic analyses of three different treatments, the checkbook, the cotton app, and the dryland were conducted, and net return above cost of irrigation, harvesting, and ginning costs were calculated by using the five years of experimental field trial data. The most economically efficient irrigation scheduling method was identified by comparing the net return of different irrigation scheduling methods. First, the gross revenue was calculated as,

$$Nominal\ gross\ revenue_{c,i,j,t}$$
$$= lint\ yield_{c,i,j,t} \times lint\ price_t + seed\ yield_{c,i,j,t} \times seed\ price_t$$

Where, c ($c = 1, \ldots, 3$) is the replicate of the irrigation i ($i = 1, \ldots, 8$) and tillage systems j ($j = conventional\ tillage, conservation\ tillage$) in each production season t ($t = 2013, \ldots, 2017$).

The harvested cotton was ginned to obtain the cotton lint yield for each plot. The conversion ratio of 1.412 units gave seed yield from the cotton lint yield. The conversion ratio was retrieved from the Cotton Loan Calculator developed by Cotton Incorporated (Falconer and Reeves, 2017). The base quality market price of cotton lint and premium or discounts for the different fiber quality for each year was obtained from Cotton Price Statistics Annual Reports (USDA-AMS, 2014, 2015, 2016, 2017, 2018) gave the base quality market price of cotton lint. In addition, depending upon the fibre quality of the cotton lint, premium or discounts were provided and the market price for each treatments were estimated. National cottonseed price was obtained from USDA, National Agricultural Statistics Service (NASS), Quickstat for each year (USDA, 2013, 2014, 2015, 2016, 2017).

For the comparison of gross revenue across the years, real values of gross revenue were obtained from their nominal values with the help of Federal Reserve Economic Data (FRED), St. Louis Fed as follows,

$$Real\ gross\ revenue_{c,i,j,t} = \left(\frac{CPI_{2017}}{CPI_t}\right) \times nominal\ gross\ revenue$$

Next, costs associated with cotton production, the cost of irrigation, harvesting, and ginning cost, had to be estimated for each treatment.. The costs of irrigation were estimated as a sum of ownership and operating costs. Ownership costs are the annual fixed costs associated with the investment costs. It includes the depreciation costs, intermediate interest costs, tax and insurance costs for pipe and fittings, pivot system, pump, power unit (for electric), gearhead system (for diesel), well, soil moisture sensors, and base station. Operating costs are the variable costs including fuel or electricity costs, repairs and maintenance costs, and labor and management costs. It varies with the amount of water applied for irrigation. For this study, 160 Acres electricity operated UGA Extension

Irrigation Budget was used to estimate the irrigation costs (Bhattarai et al., 2020). Following the cost schedule of cotton growers, the irrigation cost for the dryland control was assumed to be zero.

Yields were assumed to have a proportional relation with harvesting ginning costs (Falconer and Reeves, 2017). Ginning costs came from University of Georgia Cotton Enterprise Budget for each year (Shurley and Smith, 2013, 2014, 2015, 2016, 2017) and harvesting costs from Cotton Incorporated Cotton Loan Calculators (Falconer and Reeves, 2017). The total expenditure was calculated as,

$$Total\ expenditure_{c,i,j,t} = cost\ of\ irrigation_{c,i,j,t} + harvesting\ cost_{c,i,j,t} + ginning\ cost_{c,i,j,t}$$

Finally, the net return per hectare is calculated by using following equation,

$$Net\ return_{c,i,j,t} = real\ gross\ revenue_{c,i,j,t} - total\ expenditure_{c,i,j,t}$$

For economic analysis of each irrigation scheduling strategies, RStudio Version 1.2.5001 was used. In case of significant differences, Tukey tests were conducted among the schedules at a 95% confidence level.

4.3.4 Stochastic efficiency with respect to function (SERF)

Weather conditions in different years influence the yield and the amount of irrigation needed by different irrigation scheduling methods. This variation in yield and input usage may result in risks and volatility in the net returns for cotton producers. When facing risks, different producers may have different attitudes toward risks, and thus prefer different risky alternatives. Recognizing this, we incorporated producers' risk attitudes toward alternative farming practices into their decision-making process. In this research, we compared mutually exclusive decisions faced by cotton producers for alternative irrigation scheduling methods, including the UGA checkbook method, Cotton App, and dryland control.

Stochastic efficiency with respect to a function (SERF) analysis was used to compare the alternative irrigation scheduling methods simultaneously and identified the most preferred alternative for a given range of risk attitudes (Hardaker et al., 2004). This method has been widely used in evaluating alternative farming practices (Fan et al., 2020a, b, Liu et al., 2017, Liu et al., 2018, Wibowo et al., 2016, Williams et al., 2014). SERF ranks the risky alternatives by certainty equivalent (CE), which is calculated from the net return for each risky alternative (Williams et al., 2014). CE is the guaranteed amount of money for a risky alternative (Williams et al., 2014). In this analysis, CEs can also be viewed as the risk-adjusted value of the net return for each irrigation scheduling method. The alternative with the highest CE is the most risk preferred method by decision-makers (Hardaker and Lien, 2010, Hardaker et al., 2004, Meyer et al., 2009). Information pertaining to the utility function and risk aversion coefficients is required for the SERF analysis. In this study, a negative exponential utility function was used to represent the risk aversion behavior of cotton producers and calculate the CEs for the alternative irrigation scheduling methods. The functional form of the negative utility function is as: $U(x) = -\exp(-r_a x)$, where x is the outcome from a risky alternative and r_a is the absolute risk-aversion coefficient (Schumann et al., 2004). For this utility function, two assumptions were made. First, risk averse decision maker, tends to choose less risky alternatives than the higher risky ones provided that they outcome same expected return, and second, decision makers possess constant absolute risk aversion coefficient.

The absolute risk aversion coefficient is given by,

$$r_a = \frac{r_r}{w}$$

Where, r_a is the absolute risk aversion coefficient, r_r is relative risk aversion coefficient and it ranges from 0 to 4, and w is the average net return of the all irrigation treatments.

Negative exponential utility weighted risk premiums (RP) relative to dry land control was identified with the help of stochastic efficiency with respect to a function. For UGA checkbook and dry land control, the utility weighted risk premium (RP) can be calculated using the following equation:

$$RP_{ckb,dry,R_a} = CE_{ckb,R_{a(w)}} - CE_{dry,R_{a(w)}} \qquad (2)$$

For Cotton App and dry land control, the equation for RP is as follows:

$$RP_{cotapp,dry,R_a} = CE_{cotapp,R_{a(w)}} - CE_{dry,R_{a(w)}} \qquad (3)$$

Where, RP is the risk premium and is the minimum amount of money ($/acre) that a decision maker is willing to pay for the new alternative (Hardaker et al., 2004), CE is the certainty equivalent, ‘ckb’ is the UGA checkbook method, ‘dry’ is the dry land control, ‘cotapp’ is the cotton app method, R_a is the absolute risk aversion and ‘w’ stand for average net return.

A model called the Simulation and Econometrics to Analyze Risk (SIMETAR© version 5) created by Richardson, Schumann and Feldman (2008) was used to conduct the SERF analysis and compare the net return for different irrigation scheduling method. In this way, SERF method is used to rank the entire distribution of the net returns per acre for three different irrigation scheduling methods and the economic benefits of adopting those alternatives under different risk aversion assumptions were identified.

4.4 RESULTS AND DISCUSSION

4.4.1 Lint Yield

Figure 13 shows the result for lint yield (kg ha^{-1}) for each year. In 2013, there was no significant difference in the lint yield between the irrigation schedules. The Cotton App produced highest with 1666 kg ha^{-1} of lint, and the Checkbook produced the lowest with 1513 kg ha^{-1} of lint. However, in dry year 2014, there was significant difference in lint yield between the Control and all other irrigation schedules. The highest lint yield was resulted from the Cotton App, 2041 kg ha^{-1}. In 2015 and 2016, significant difference was observed between the Checkbook and Control. In both years, highest lint yield was obtained from the Control. Finally, in 2017, lint yield was significantly lower for the Checkbook than the Cotton App including the Control. In all wet years, lint yield was found to be lowest for checkbook. Similarly, lint yield was highest in the control except for 2013. This suggests that when there is enough rainfall in the growing season farmers can choose not to irrigate their field. However, farmer can get more lint yield, if they opt to irrigate their field using modern irrigation schedules rather than the calendar based checkbook method. Table 12 shows the summary of statistics of lint yield for each treatments. The average lint yield from all the years revealed to have no significant difference. The highest lint yield was observed for the Cotton App (1611 kg ha^{-1}). This shows that the Cotton App may have the potentiality to produce more lint per hectare.

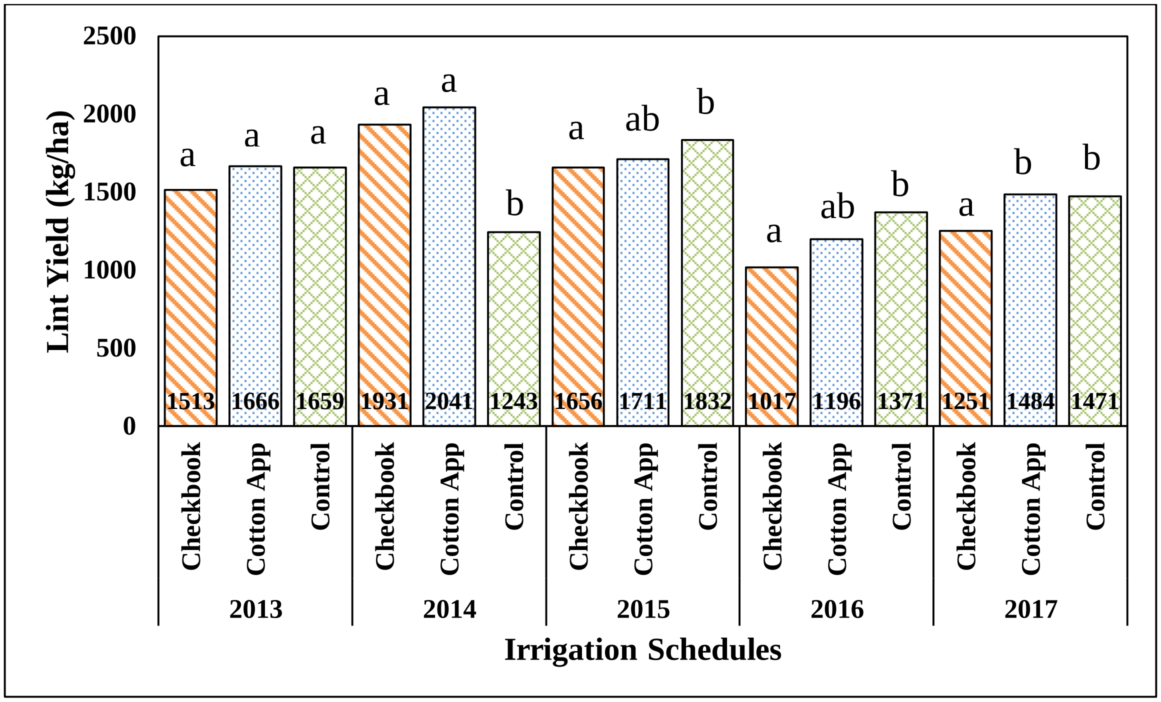

Figure 13: Lint yield of the Control, the Checkbook, and the Cotton App across the years

Within a given year, means for different irrigation treatment followed by the same letter are not significantly different from each other at P<0.05.

Table 12: Summary of statistics for lint yield across the Control, the Checkbook, and the Cotton App.

Treatment	Mean	S.D	Min	Max
	----------------------Kg Ha^{-1}	----------------------		
Control	1490[a]	296	828	2099
Checkbook	1467[a]	437	835	3019
Cotton App	1611[a]	395	938	2888

Means for different irrigation treatment followed by the same letter are not significantly different from each other at P<0.05.

4.4.2 Irrigation Costs

Table 13 shows the total precipitation in each year, amount of irrigation given to each treatment across the year, and total water for each treatment in mm. For each year checkbook received the highest amount of water. 160 acres electric irrigation budget was used to estimate the ownership and operating costs of each irrigation schedules across the years. The irrigation cost results are portrayed in Figure 14. Irrigation costs were significantly higher for the Checkbook than other treatments in all years suggesting that farmer can lower their production costs by adopting modern irrigation scheduling method like the Cotton App.

Table 13: Rainfall, irrigation amount, and total water for different irrigation scheduling methods across the years.

Year	Treatment	Rainfall	Irrigation	Total Water
		----------------- mm -----------------		
	Control	696	38	734
2013	Checkbook	696	323	1019
	Cotton App	696	76	772
	Control	285	97	382
2014	Checkbook	285	387	672
	Cotton App	285	231	516
	Control	574	13	587
2015	Checkbook	574	165	739
	Cotton App	574	127	701
	Control	650	19	669
2016	Checkbook	650	203	853
	Cotton App	650	133	783
	Control	617	13	630
2017	Checkbook	617	241	858
	Cotton App	617	114	731

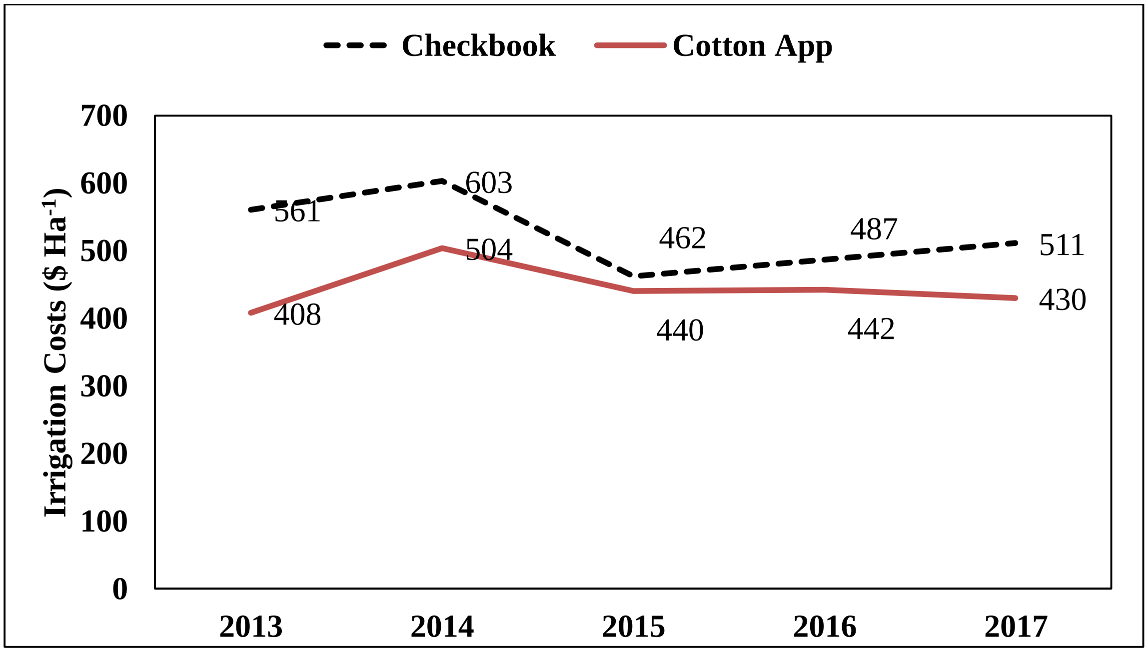

Figure 14: Irrigation Costs for different irrigation scheduling method across the years using 160 acres electric irrigation budget.

4.4.3 Net Return

Figure 15 shows the net return for each treatments. In 2013, the Control gave significantly higher net return than the Checkbook. In 2014, which was a dry year, the Cotton App resulted significantly higher net returns than the Control. The net return for the Cotton App (2554 $\$$ ha^{-1}) was highest among other. In 2015 and 2016, net return for the Control was found significantly higher than the Checkbook and the Cotton App method. For 2017, the net return of the Checkbook was significantly lower than the Cotton App and the Control.

These results suggested that when there is enough rainfall during the growing season, the irrigation can hurt the yield and profitability. However, it was more profitable for farmers to use advance irrigation scheduling system rather than the calendar based checkbook method. In case of dry year, the it was beneficial for growers to use irrigation scheduling methods, since it increased yield and profitability.

Table 14 shows the summary of statistics of net return for each treatments. The average net return from all the years revealed to have significantly higher net return for the control treatment than other two treatments. The Cotton App resulted significantly higher net return than the Checkbook. The highest net return was observed for the Control (2364 \$ ha^{-1}) and the lowest for the Checkbook (1781 \$ ha^{-1}). This shows that the Cotton App, a modern irrigation scheduling method, can be economically efficient method than the calendar based checkbook method.

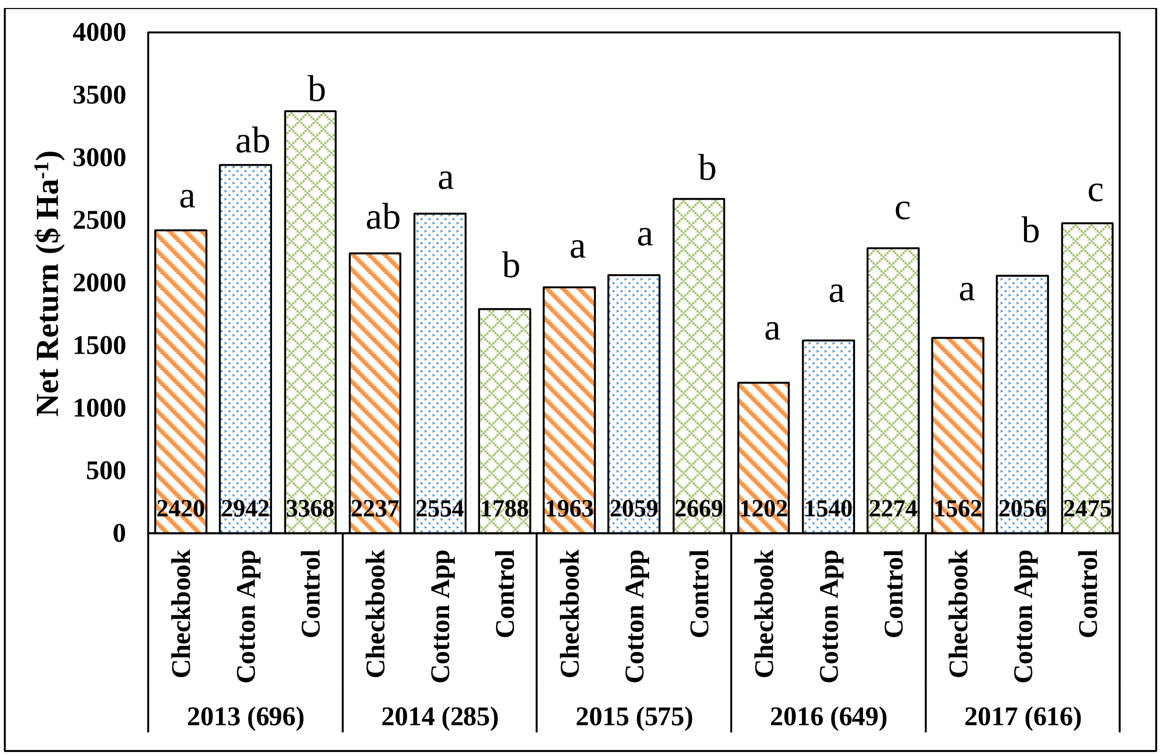

Figure 15: Net return of the Control, the Checkbook, and the Cotton App across the years.

Within a given year, means for different irrigation treatment followed by the same letter are not significantly different from each other at $P<0.05$.

Table 14: Summary of statistics of net return for the Control, the Checkbook, and the Cotton App.

Treatment	Mean	S.D	Min	Max
	-----------------------$ Ha^{-1}-----------------------			
Control	2364[a]	505	1228	3752
Checkbook	1781[b]	568	1021	3727
Cotton App	2105[c]	571	1113	3882

Means for different irrigation treatment followed by the same letter are not significantly different from each other at $P<0.05$.

4.4.4 SERF results

The stochastic efficiency results showed that, under a negative exponential utility function, the Control had the highest certainty equivalent for all the risk aversion level than the checkbook and the Cotton App. The absolute risk aversion coefficient ranged from 0 being the risk neutral to 0.002 being the most risk averse. The checkbook method resulted in the lowest certainty equivalent among the risk neutral growers. Figure 16 shows the result of SERF when 160 E irrigation budget is used.

This showed that for all level of risk averse cotton growers, the Control was preferred. But if the cotton growers had to choose between the Checkbook and the Cotton App, they will be better off with the Cotton App.

To switch from one alternative to another, growers have to be paid a minimum amount of payment called risk premiums. Figure 17 is the graph showing utility weighted risk premiums relative to dry land control. For the Cotton App it ranged from -$108 to -$147 per hectare. Similarly, for the Checkbook it was -$358 to -$407 per hectare. The negatively valued risk premium resembled that the Cotton App and the Checkbook are not preferred by the growers. This strange result may have been obtained because, there was only single dry year in this study and other remaining were the wet years. Therefore, the field data might not have captured the wider range of weather variability. Another explanation can be that, no irrigation cost (ownership and operating costs) was included for the Control even though irrigation was provided to the dry plots. The irrigation was provided before the cotton were planted in the field for two main reasons. First, to activate the herbicide, and second to promote the germination of the cotton.

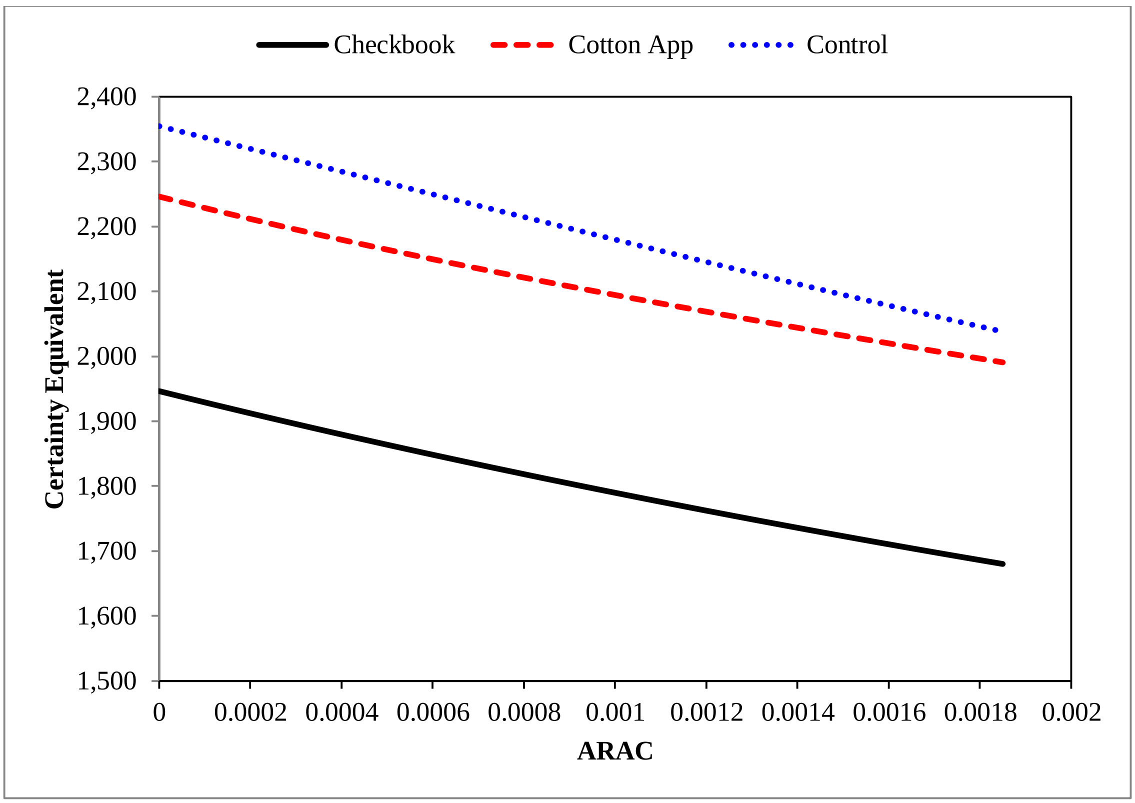

Figure 16: Certainty equivalents ($/ha) of cotton app, checkbook and dryland.

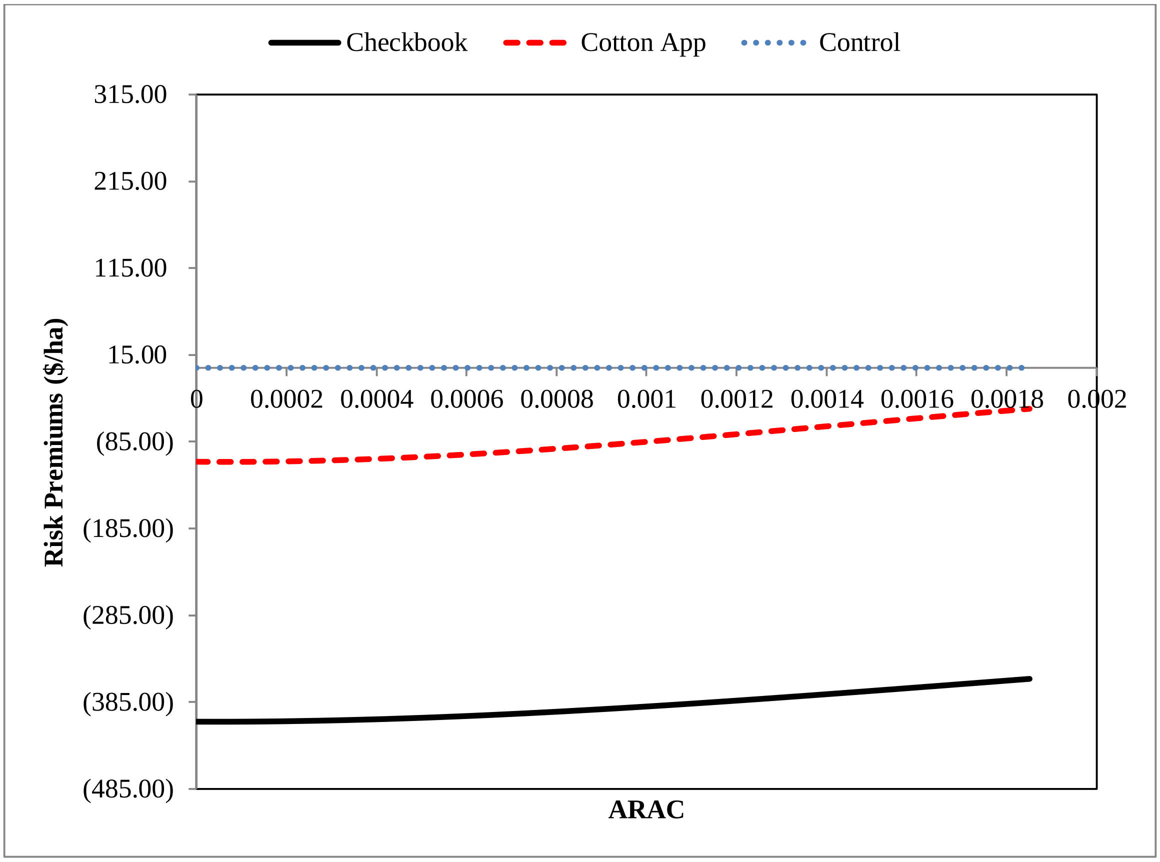

Figure 17: Risk premiums ($/ha) of the cotton app and checkbook method (base treatment is dry land control).

Table 15 depicts the utility weighted risk premiums for the Checkbook and the Cotton App with respect to the Control across the 5 levels of absolute risk aversion coefficient. For both irrigation scheduling methods, the risk premiums value were found to be negative across all risk aversion level. This made the rainfed condition more risk efficient than the irrigation scheduling methods.

Table 15: Risk premiums (RPs) for the Checkbook and Cotton App relative to the Control using absolute risk aversion coefficient (ARAC)

Risk Aversion Level	ARAC	Irrigation Method	
		Checkbook	Cotton App
		------------------$ Ha^{-1}------------------	
Risk neutral	0	(407)	(108)
Somewhat risk averse	0.00046	(404)	(104)
Rather risk averse	0.00093	(392)	(88)
Very risk averse	0.00139	(376)	(68)
Extremely risk averse	0.00185	(358)	(47)

With respect to the Checkbook, the risk premium for Cotton App was found to be \$299 to \$311 per ha (Figure 18). From this it's clear that the Cotton App is preferred over the Checkbook. As the growers become more risk averse then they are more likely to adopt the Cotton App.

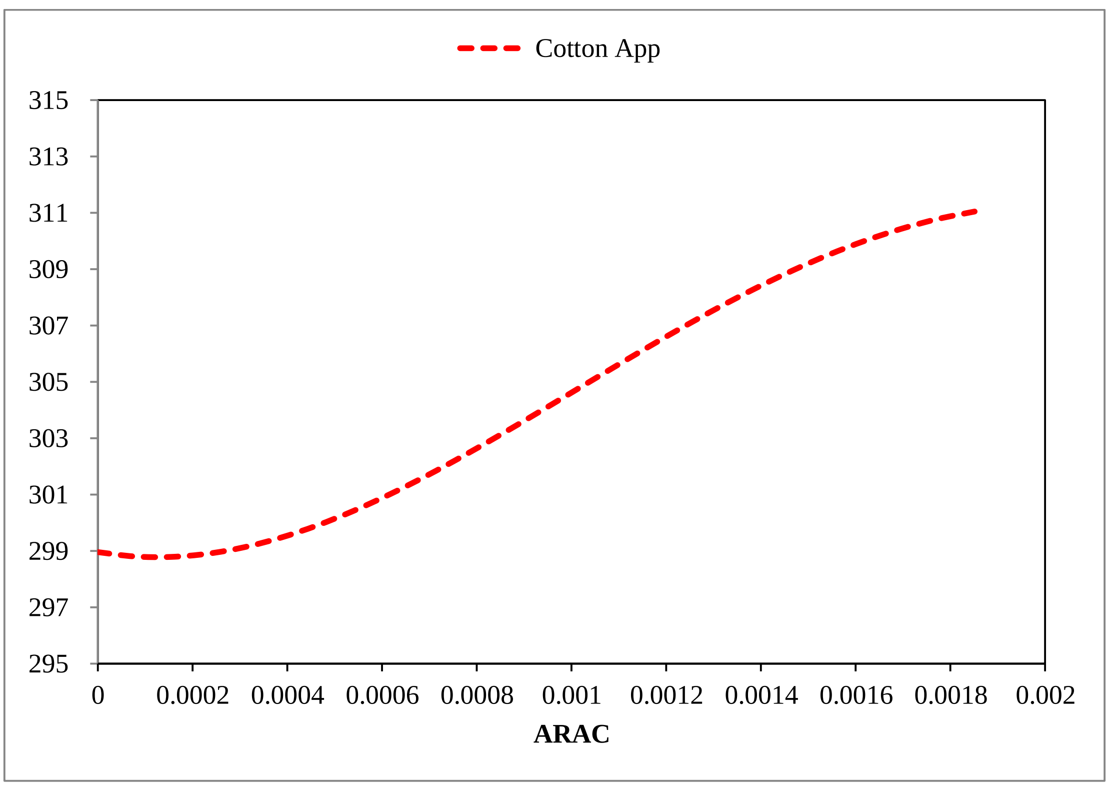

Figure 18: Risk premiums (\$ ha^{-1}) of Cotton App with respect to Checkbook

4.5 SENSITIVITY ANALYSIS

This section will portray the impact of using four different UGA extension irrigation budgets on the net return and the risk premiums. 160 acres electric (160 E), 160 acres diesel (160 D), 65 acres electric (65 E), and 65 acres diesel (65 D) are the four irrigation budgets used to estimate the irrigation costs for different treatments in different years.

4.5.1 Impact on the Irrigation Costs

Four different UGA Extension Irrigation Budget were used to estimate the ownership and operating costs of each irrigation schedules across the years. The irrigation cost results are portrayed in Table 16. Across the different irrigation budgets, irrigation costs were lowest for 160 E, and highest for 65 D. Pivot system covering larger area will have lesser ownership and operating costs per hectare. Furthermore, if the system is operated by electricity, the energy cost will comparatively lesser than the diesel operated system. This might be the reason behind lesser irrigation costs for the 160 E followed by 160 D, 65 E, and finally, 65 D for an increasing order.

4.5.2 Impact on the Net Return

Table 17 displays the net return from four different irrigation budgets. The net returns were found highest from 160 E irrigation budget, and gradually decreased for 160 D, 65 E, and 65 D. Increased irrigation cost resulted this condition.

For 160 D, the significance result was same as 160 E in all wet years, except for 2014. In 2014, no significant difference was found between the treatments. Same was the case for 65 E in 2014. However, when the 65 E irrigation budget was used, in 2013 and 2015, the Control resulted significantly higher net return than the other two treatments.

Table 16: Irrigation amount and irrigation costs for different treatments across the years using different irrigation budgets.

Year	Treatment	Type of Irrigation Budgets			
		160 E	160 D	65 E	65 D
		-----------------------$ Ha^{-1}-----------------------			
2013	Checkbook	561	804	981	1216
	Cotton App	408	500	796	942
2014	Checkbook	603	883	1030	1288
	Cotton App	504	692	912	1115
2015	Checkbook	462	611	862	1040
	Cotton App	440	564	833	998
2016	Checkbook	487	658	892	1082
	Cotton App	442	571	838	1006
2017	Checkbook	511	705	919	1124
	Cotton App	430	547	823	984

Table 17: Net return ($ ha^{-1}) for checkbook, cotton app and dry land across years.

Year	Treatment	Type of Irrigation Budgets			
		160 E	160 D	65 E	65 D
		-----------------------$ Ha^{-1}	-----------------------		
2013	Checkbook	2420[a]	2178[a]	2000[a]	1766[a]
	Cotton App	2942[ab]	2850[ab]	2554[a]	2408[b]
	Control	3368[b]	3368[b]	3368[b]	3368[c]
2014	Checkbook	2237[ab]	1958[a]	1809[a]	1552[a]
	Cotton App	2554[a]	2366[a]	2146[a]	1944[a]
	Control	1788[b]	1788[a]	1788[a]	1788[a]
2015	Checkbook	1963[a]	1814[a]	1562[a]	1384[a]
	Cotton App	2059[a]	1935[a]	1666[a]	1500[a]
	Control	2669[b]	2669[b]	2669[b]	2669[b]
2016	Checkbook	1202[a]	1032[a]	798[a]	607[a]
	Cotton App	1540[a]	1415[a]	1148[b]	980[b]
	Control	2274[b]	2274[b]	2274[c]	2274[c]
2017	Checkbook	1562[a]	1368[a]	1153[a]	948[a]
	Cotton App	2056[b]	1942[b]	1665[b]	1504[b]
	Control	2475[c]	2475[c]	2475[c]	2475[c]

Within a given year, means for different irrigation treatment followed by the same letter are not significantly different from each other at $P<0.05$.

4.5.3 Impact on the Certainty Equivalent and Risk Premiums

Figure 19 shows the risk premiums of the Cotton App with respect to the Checkbook across different absolute risk aversion coefficient. The figure shows that, as the risk aversion level increase, the cotton growers are more likely to adopt the Cotton App in case of 160 acre electric budget. However, in case of 160 acre diesel, 65 acres diesel, and 65 acres electric, growers are less likely to adopt the Cotton App, as the risk aversion level increase.

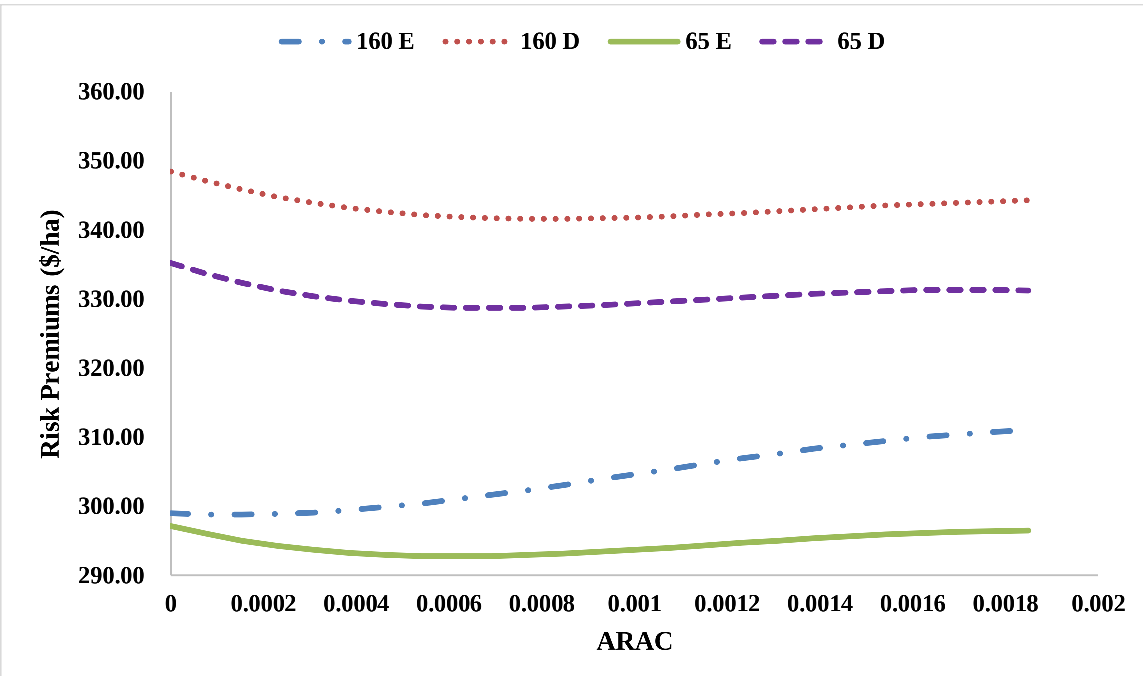

Figure 19: Risk premiums ($/ha) for Cotton app relative to the Checkbook

Table 18 depicts the utility weighted risk premiums for the Cotton App with respect to the checkbook across the 5 levels of absolute risk aversion coefficient. For 160 E, the risk premiums gradually increased when the risk aversion level increased suggesting that growers are more likely to adopt the Cotton App as the risk aversion level increase.

However, when other irrigation budgets were used to estimate the irrigation costs, the risk premiums decreased when the risk aversion level increased.

Table 18: Risk premiums (RPs) for the Cotton App relative to the Checkbook using absolute risk aversion coefficient (ARAC)

		Type of Irrigation Budgets			
Risk Aversion Level	ARAC	160 E	160 D	65 E	65 D
		--------------------$ Ha^{-1}--------------------			
Risk neutral	0	299	349	297	335
Somewhat risk averse	0.00046	300	343	293	329
Rather risk averse	0.00093	304	342	293	329
Very risk averse	0.00139	308	343	295	331
Extremely risk averse	0.00185	311	344	297	331

4.6 CONCLUSIONS

The net returns of smart irrigation cotton app, UGA checkbook and dry land control were examined from 5 years (2013 to 2017) of field experimental data in cotton field of Camilla Georgia. SERF was used to analyze the risk associated with the alternatives. Results showed that dry land condition was the most risk efficient for cotton growers to increase risk-adjusted net return. Cotton growers will be better off to adopt modern irrigation scheduling method rather than using the calendar based checkbook method. The main barricade for the adoption of new technology by the growers is that they are unaware about the risk associated with adoption of that technology. This study revealed the risk efficiency value of each irrigation scheduling methods and demonstrated that the Cotton App had higher risk efficiency value than the Checkbook. This would ultimately help growers in adopting modern irrigation scheduling method, increasing yield and net return, and improving irrigation water use efficiency.

CHAPTER 5 CONCLUSIONS

This study investigated the efficiency and sustainability of adopting modern irrigation scheduling methods for cotton production. Several methods have been developed at the University of Georgia to increase water use efficiency and cotton productivity. These methods include the UGA checkbook method (Checkbook), smart irrigation cotton app (Cotton App), UGA smart sensor array (UGA SSA), cotton water stress index (CWSI), and Irrigator Pro. The economic study of this research uses the data from a five-year field experiment (2013 to 2017) at the University of Georgia C.M. Stripling Irrigation Research Park in Camilla, Georgia (Latitude: 31.281632, Longitude: -84.294388).

This thesis first investigated the economic efficiency of the five irrigation scheduling methods. Results revealed that the choice of modern irrigation scheduling methods like the Cotton App, and UGA SSA could help cotton growers in increasing yield and profitability over the calendar based checkbook methods. The cotton yield and profitability were greatly affected by climatic factors such as rainfall. Higher precipitation in the growing season accompanied by the irrigation hurt the yield and profitability. However, significantly higher profits were obtained when the field was irrigated during the dry year.

Even though the economic profitability of modern irrigation scheduling systems is higher than the traditional methods, barriers still exist for growers to adopt due to lack of information related to the risk associated with the new methods. Identifying the risk in terms of monetary value can be beneficial in helping producers in their decision making process and increase the adoption rate. The second objective of this research was to investigate the economic benefits of adopting more advantage irrigation scheduling systems by considering the risk preference of individual producers. Two irrigation scheduling methods were compared with dryland control under conservation tillage, including the Checkbook and the Cotton App methods. The certainty equivalent was highest for the Control across all risk aversion coefficients. This result indicated that using irrigation scheduling practices is less profitable and risk efficient compared to the rainfed. This is largely due to the production costs, especially fixed costs, associated with owning the irrigation systems. Another reason is that for conservation tillage, the cover crops increase the water holding capacity of the soil. This maintains the good amount of moisture in the soil required for cotton plant to produce more. Addition of extra water through irrigation hurt the yield and profitability for conservation tillage. Therefore, in normal rainfed condition, the yield was found to be higher for conservation tillage than the conventional tillage. Furthermore, assuming the cost of irrigation to be zero, even though the irrigation was applied in the field trial, is another reason for rainfed condition to outperform other treatments in net return. This assumption was made to mimic the rainfed farms of the growers where they do not irrigate the farm at all. However, if the growers already have central pivots installed in their farm, they will more likely irrigate their fields. Our analysis shows that the certainty equivalent for Cotton App were higher than the Checkbook method. Therefore, using appropriate efficient irrigation scheduling methods can increase the profitability and mitigate the production risks. As it is known that 25.4 mm (1 inch) of irrigation water in one hectare of land contain 67,098 gallons of water, reduction in the depth or amount of irrigation even by 1 inch can save 38,016 million gallons of water in Georgia alone. Depending upon the soil type, the average depth of irrigation for cotton is 305-355 mm (12-14 inches) in the checkbook irrigation scheduling methods but the average irrigation depth for UGA SSA and Cotton App methods used in our study is 127-178 mm (5-7 inches). Looking at this, there will be reduction of 5-9 inches of irrigation water per hectare saving 190,080 million to 342,144 million gallons of water in Georgia. Hence, use of the UGA SSA and Cotton App can bring sustainability in the production.

The additional time and money might be required for the new irrigation practices, and it might seem overwhelmingly costlier in the beginning. However, over the course of time, adopting modern irrigation practices will be necessary to ensure the long-term sustainability for cotton production. Higher lint yield, and net return were obtained when the cotton growers use efficient modern irrigation scheduling strategies than the older, and less efficient calendar based methods.

Although adopting modern conservation practices could produce more benefits, growers are always doubtful about the new technology, and they might not possess the high initial costs required for the new technology. These initial investments do not have the guaranteed return. Furthermore, farming tradition might be another great issue that hinders the adoption decision. As long as these doubts remain among the growers, adoption rate might be low. However, the results of this study have shown that risk value of the modern irrigation scheduling method is higher than the traditional method. This goes without saying, the modern irrigation scheduling methods studied in this research can potentially be beneficial for the producers.

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APPENDIX

160 Acre Electric Engine Center Pivot Irrigation Budget
Georgia, 2020

No. of Pivots on Your Farm	2
No. of Towers per Pivot	8
Acreage Covered (Acres)	160
Hours for Full Circle (Hours)	73
Crop Type	Corn
Irrigation scheduling Method[1]	Checkbook
Acre Inch Applied (Inch)	12

Investment Costs

	Useful Life	Salvage Value	Quantity	Cost/Unit	Investment Cost	Investment Costs Per Acre
Pipe and Fittings (Feet)	20	0	500	$7.75	$3,875.00	$24.22
Pivot System	20	0	8	$12,000.00	$96,000.00	$600.00
Installation			1	$9,500.00	$9,500.00	$59.38
Pump	15	0	1	$33,000.00	$33,000.00	$206.25
Power Unit	15	0	1	$17,000.00	$17,000.00	$106.25
Well[2]	20	0	1	$53,000.00	$53,000.00	$331.25
Total Investment Costs					$212,375.00	$1,327.34

Ownership Costs

	Depreciation[3]	Intermediate Interest[4] 8.00%	Tax & Insurance[5] 2.50%	Ownership Costs	Ownership Costs Per acre
Pipe and Fittings	$193.75	$155.00	$48.44	$397.19	$2.48
Pivot System	$4,800.00	$3,840.00	$1,200.00	$9,840.00	$61.50
Pump	$2,200.00	$1,320.00	$412.50	$3,932.50	$24.58
Power Unit	$1,133.33	$680.00	$212.50	$2,025.83	$12.66
Well	$2,650.00	$2,120.00	$662.50	$5,432.50	$33.95
Total Ownership Costs				$21,628.02	$135.18

Operating Costs

	Horse Power	Cost Per Unit ($/kWh)	Total	Operating Costs Per Acre	Operating Costs Per Acre Inch
Electricity	60	$0.13	$5,199.21	$32.50	$2.71
Repairs and Maintenance Costs[6]			$1,225.00	$7.66	$0.64
	Hours	Cost Per Hour			
Labor Cost	0.28	$13.25	$7,208.00	$45.05	$3.75
Management Cost	10.00	$34.21	$342.10	$2.14	$0.18
Total Operating Costs			$13,974.31	$87.34	$7.28

	Cost Per Acre Inch	Cost Per Acre	Annual Costs
Total Ownership Costs		$135.18	$21,628.02
Total Operating Costs	$7.28	$87.34	$13,974.31
Total Annual Costs		$222.51	$35,602.34

Figure 20: 160 acres electric engine center pivot irrigation budget

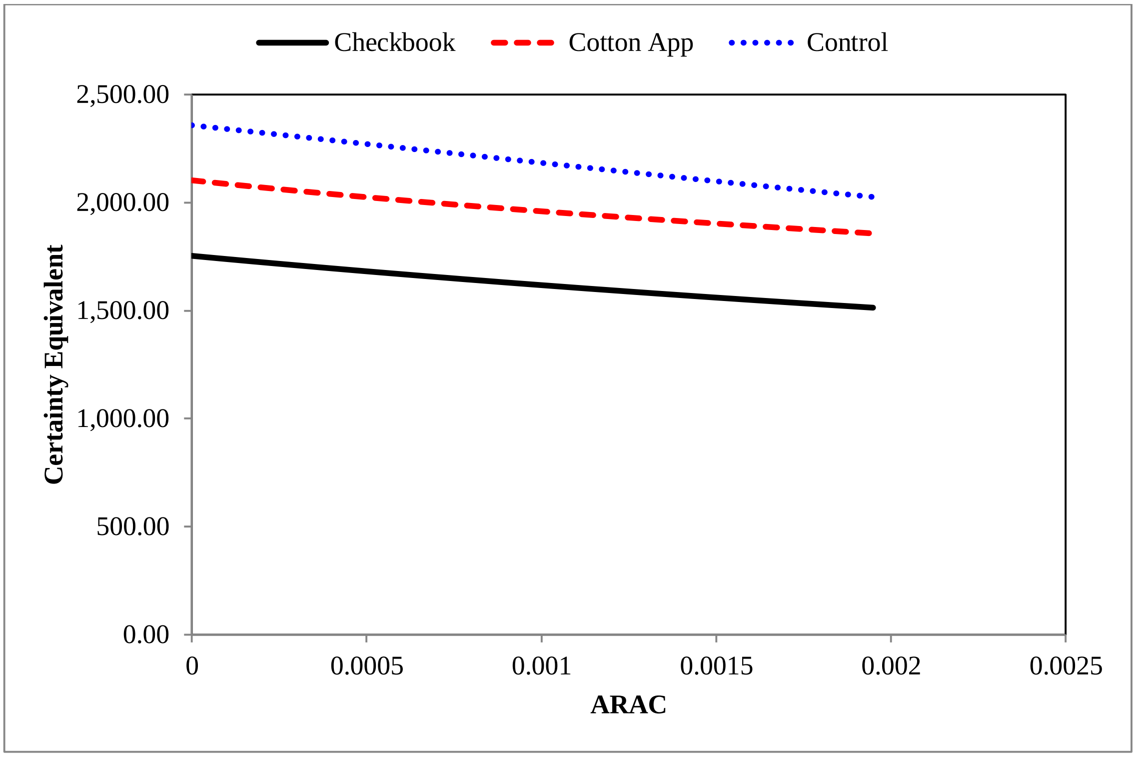

Figure 21: Certainty equivalents ($ ha^{-1}) of cotton app, checkbook and dry land using 160 D

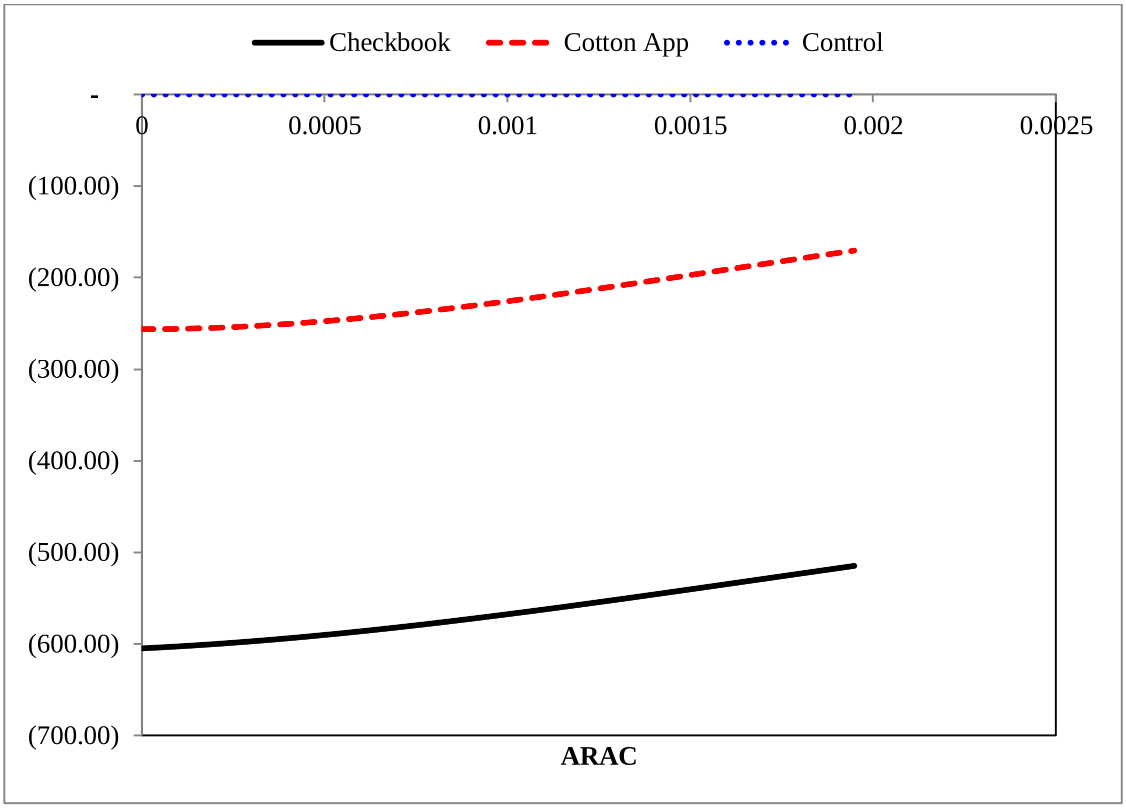

Figure 22: Risk premiums ($ ha^{-1}) of the cotton app and checkbook method (base treatment is dry land control) using 160 D

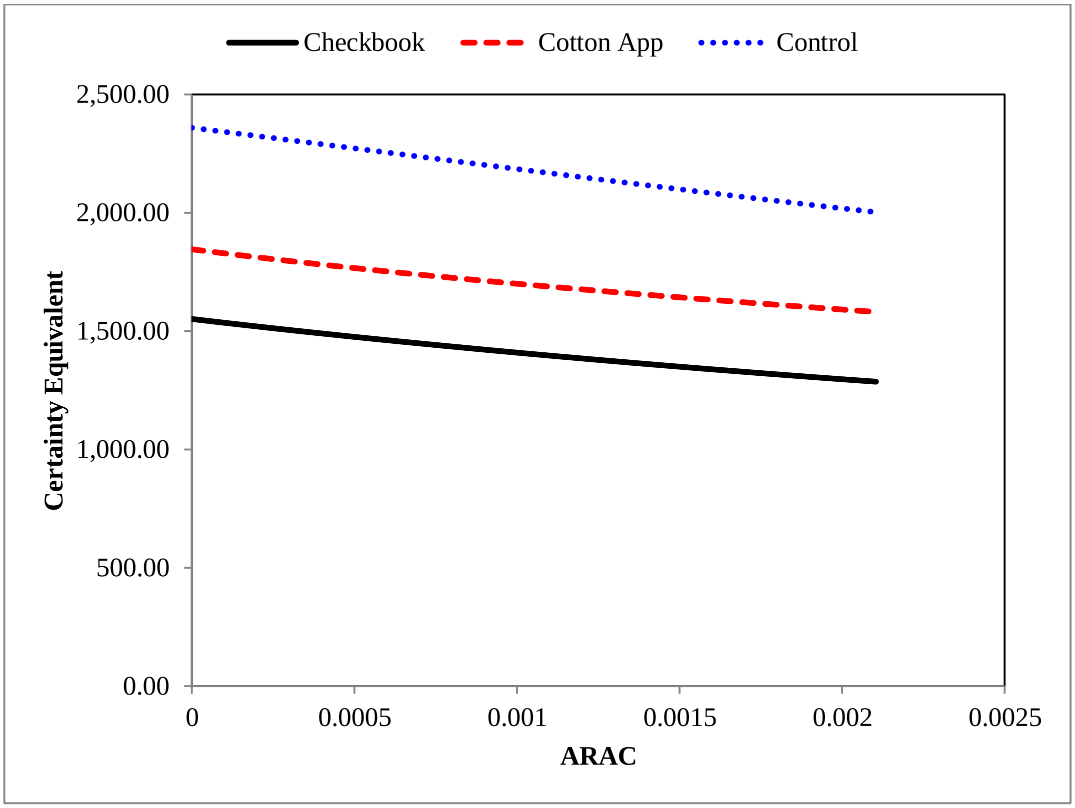

Figure 23: Certainty equivalents ($ ha^{-1}) of cotton app, checkbook and dry land using 65 E

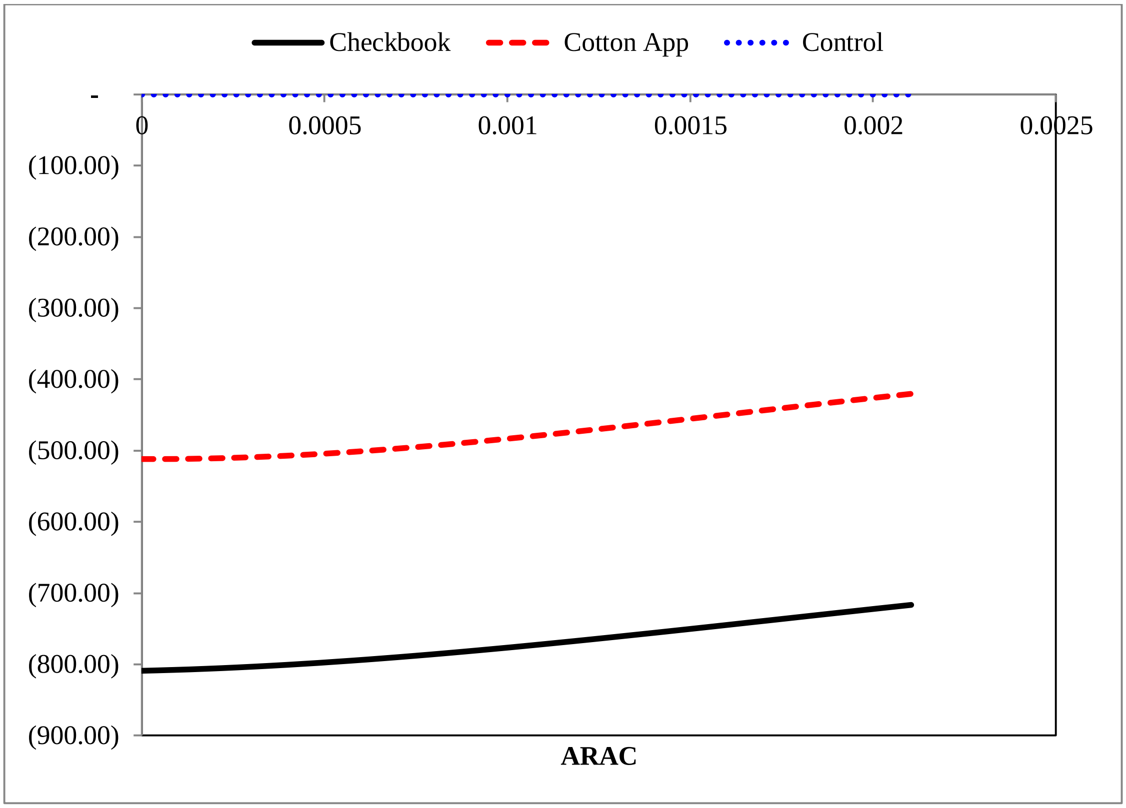

Figure 24: Risk premiums ($\$ ha^{-1}$) of the cotton app and checkbook method (base treatment is dry land control) using 65 E

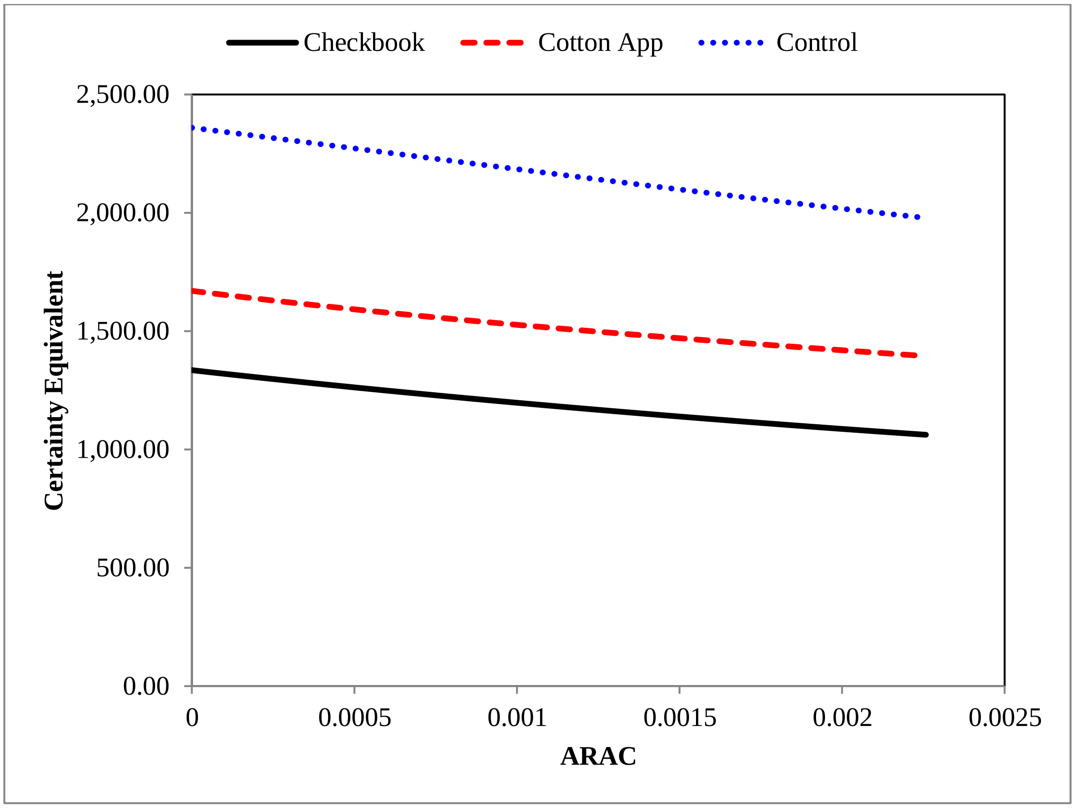

Figure 25: Certainty equivalents ($ ha^{-1}) of cotton app, checkbook and dry land using 65 D

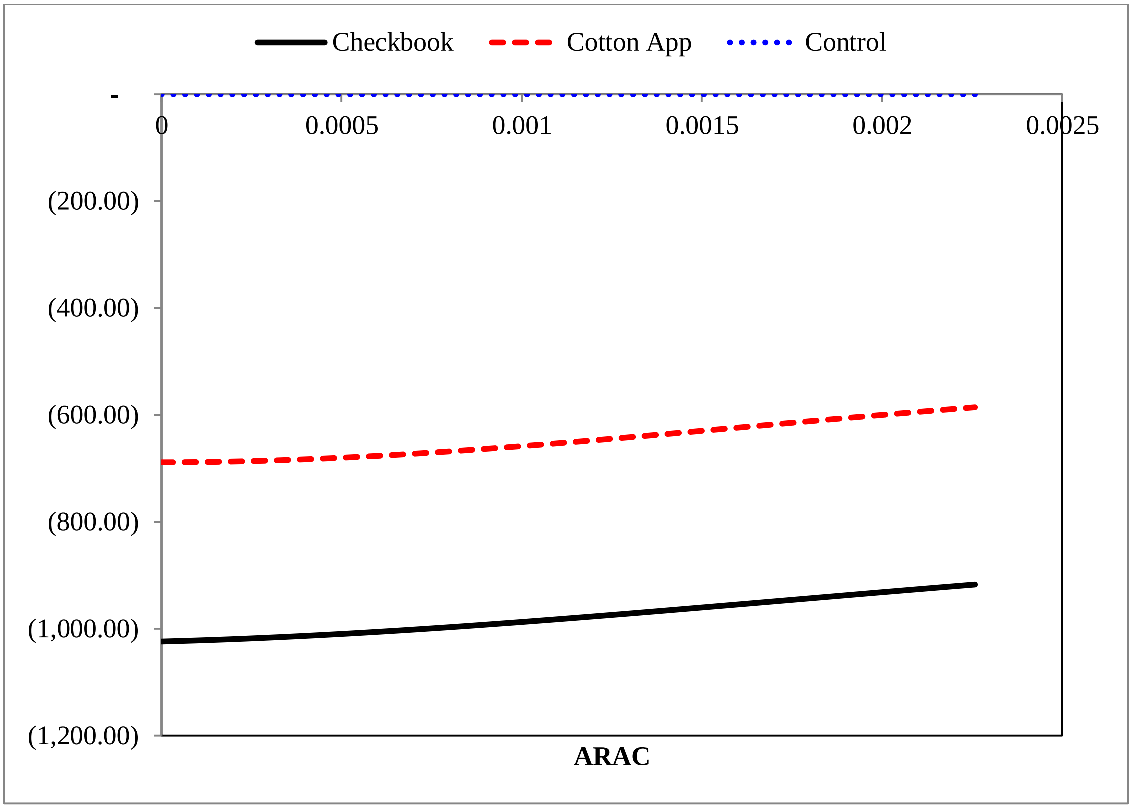

Figure 26**:** Risk premiums (\$ ha^{-1}) of the cotton app and checkbook method (base treatment is dry land control) using 65 D