Predicting Water Demand for Irrigation under Varying Soil and Weather Conditions

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Abstract

Recent issues that affect water resources in the state of Georgia include the tri-state (Alabama, Florida and Georgia) water dispute, the continuing drought in the southeastern USA, and the rapidly increasing water use by agriculture through irrigation. An understanding of water needs by agriculture is critical to ensure the availability of water for future users. The objective of this study was to evaluate crop yield response to irrigation for different soil and weather conditions using the EPIC crop model. Yield predictions showed the highest variation for rainfed conditions, while the annual yield variability was greatly reduced when irrigation was applied. Rainfed yield was lowest for the Troup loamy sand and was highest for the Dothan loamy sand. For maximum yields under non-stress conditions, the Fuquay sand had the highest irrigation demand while the Dothan loamy sand had the lowest irrigation demand. Cotton yield showed a linear increase with an increase in total irrigation until maximum yield was reached under non-stress conditions. The Troup loamy sand and Fuquay sand showed the greatest range in yield response to an increase in total irrigation. For the Dothan loamy sand, there was little increase in yield with an increase in total irrigation. This study showed that the EPIC model can be a useful tool for determining water demand for irrigation at a farm level for different soil and weather conditions. Future efforts will focus on using the model for regional estimation of water use for irrigation in Georgia.

Introduction

Recent issues that affect water resources in the state of Georgia include the tri-state water dispute between Alabama, Florida and Georgia, the continuing drought in the southeastern USA, and the rapidly increasing water use in agriculture through irrigation. An understanding of water needs by agriculture is critical to ensure the availability of water for future users. In Georgia, agricultural irrigators are required to have a permit, but they are not required to report their water use. Over 20,000 permits have been issued, and nearly 2,000 new applications are pending in the Flint River basin alone. Approval of these new applications depends on a better understanding of water use for irrigation, outcomes of the tri-state negotiations for a water allocation formula, and effects of the current drought and pumping on river flows (Thomas et al., 2000). Unfortunately, how much water is required and how much is actually being used for irrigation is currently unknown. The Georgia Department of Natural Resources, Environmental Protection Division, the designated state regulatory agency, therefore has to rely on estimates of water needs by agriculture for its water management decisions.

Computer simulation models have been developed to predict yield and water use under different irrigation and other management practices for specific sites where soil and weather information are available. With this predictive ability, water management decisions can be evaluated at a field level. In addition the impacts of plans and policies on regional agricultural water needs and production can also be determined. The objective of this study was to demonstrate the use of a computer simulation model for evaluating crop yield response to irrigation for different soil and weather conditions.

Environmental Policy Integrated Climate model

The Environmental Policy Integrated Climate (EPIC) model is a computer simulation model that can be used to determine the effect of management strategies on agricultural production and soil and water resources. The drainage area considered by EPIC ranges from a field to about 100 ha area, where weather, soils, and management systems are assumed to be homogeneous. EPIC has a single crop model that handles multiple crops and components to simulate the soil and plant water and nitrogen and phosphorus balance, and crop and soil management. (Williams et al., 1989; Meinardus et al., 1998). Inputs for EPIC include data on weather variables, crop parameters, soil parameters, and crop and soil management practices. EPIC is driven by observed and/or simulated daily weather inputs that include total solar radiation, maximum and minimum air temperature, total precipitation, average relative humidity, and average wind speed. An option to simulate rainfed or irrigated conditions is provided in EPIC. Irrigation may be scheduled by the user or can be conducted automatically by the model. With the automatic option, the model decides when and how much water to apply based on a set of thresholds defined by the user. Required inputs for the automatic version include a signal to trigger water applications and the maximum amount per application. The three options to trigger automatic irrigation are plant water stress level, plow layer soil water tension in kPa, and rootzone soil water deficit in mm. For the plant water stress level option, automatic irrigation is triggered whenever the crop water stress factor reaches a predetermined value between 0 and 1, with 1 representing no stress and 0 indicating complete cessation of transpiration.

Methods

Tifton, Georgia was selected as the study site, with 22 years (1980-2001) of long-term historical weather data. Observed solar radiation, maximum and minimum air temperature, and precipitation were collected from the weather station that is located in the Coastal Plain Experiment Station. This weather station is part of the Georgia Automated Environmental Monitoring Network (www.Georgiaweather.net; Hoogenboom, 2001). The remaining weather inputs were generated using monthly weather statistics for the closest weather station available in the EPIC weather generator parameter database. Five soils, representative of the sandy and loamy sandy soils of the Coastal Plain region, were used to define the soil inputs. Values for various soil parameters at different depths were obtained from the soil survey report of the Georgia Agricultural Experiment Stations (Perkins et al., 1986). The amount of water in the soil that can be extracted by the plant depends on soil physical characteristics as well as rooting depth. For the selected soils, total extractable soil water varied from 3.1 inches for the Troup loamy sand to 5.3 inches for the Carnegie loamy coarse sand (Table 1). Among the five soils, the Troup loamy sand had the highest hydraulic conductivity, followed by the Fuquay sand. The Carnegie loamy coarse sand, Dothan loamy sand, and Tifton loamy sand had very low hydraulic conductivity in the lower part of the subsoil. Cotton, one of the most important crops in Georgia with a harvested area of about 3.46 million acres for the year 2000 (www.nass.usda.gov/ga), was selected for this study. Crop and soil management practices, which include land preparation, planting and harvesting dates and fertilizer application, were obtained from the variety trial reports of the Georgia Agricultural Experiment Stations (Day et al., 1999; Day et al., 2000; Day et al., 2001; Day et al., 2002; Raymer et al., 1991; 1992; Raymer et al., 1993; 1994; Raymer et al., 1995; 1996; Raymer et al., 1997; Raymer et al., 1998).

The simulation was set at one year and was initiated on January 1. Initial soil water content was estimated automatically by the model based on average annual rainfall. The plant water stress level option was selected to trigger automatic irrigation. Threshold values for triggering irrigation varied from 0.1 to 1, with 1 corresponding to fully irrigated (non-stress) conditions. Maximum amount per application was set to 1.18 inches. A sprinkler irrigation efficiency of 75% was assumed. Crop yield for rainfed conditions was also evaluated.

Table 1. Total extractable soil water and saturated hydraulic conductivity for the five soils.

Soil	Total Depth (inches)	Extractable Soil Water (inches)	Depth Below Soil Surface (inches)	Saturated Hydraulic Conductivity (inches/hour)
Carnegie Loamy Coarse Sand	83.9	5.3	5-17	0.8-3.9
			32-45	0
Dothan Loamy Sand	83.9	3.9	5-17	1.1-7.0
			32-45	0.1-0.2
Fuquay Sand	83.9	4.4	5-17	5.4-7.1
			32-45	1.6-7.1
Tifton Loamy Sand	83.9	4.1	5-17	1.9-5.6
			32-45	0.0-0.4
Troup Loamy Sand	94.1	3.1	5-17	6.4-12.8
			32-45	8.6-12.1

Results

Crop yield is determined by numerous interacting factors. One of the main causes for yield variability of rainfed crops is the annual variation in precipitation. In this study, the total rainfall during the growing season (April-October) ranged from 7.5 inches in 1997 to 38.1 inches in 1994. The average rainfall was 18.5 inches and the standard deviation was 5.9 inches. Figure 1 shows that for rainfed cotton, the highest yield was obtained in 1994, the growing season with the highest total rainfall. The lowest yield was obtained in 1997, the growing season with the lowest total rainfall. The simulated yields for rainfed cotton were highly variable for all soils except the Dothan loamy sand (Figure 1). In contrast, for fully irrigated (non-stress) cotton, EPIC predicted a fairly stable yield from 1980 to 2001 for all soils (Figure 2).

Yields for rainfed cotton were between 188 and 580 lb/acre less when compared with fully irrigated (non-stress) conditions (Table 2). Rainfed yield was lowest for the Troup loamy sand; the soil with the lowest extractable soil water and the highest hydraulic conductivity. Rainfed yield was highest for the Dothan loamy sand. For all soils, yield predictions showed a higher deviation from the mean for the rainfed conditions compared with the irrigated conditions. For maximum yields under non-stress conditions, the Fuquay sand had the highest irrigation demand while the Dothan loamy sand had the lowest irrigation demand.

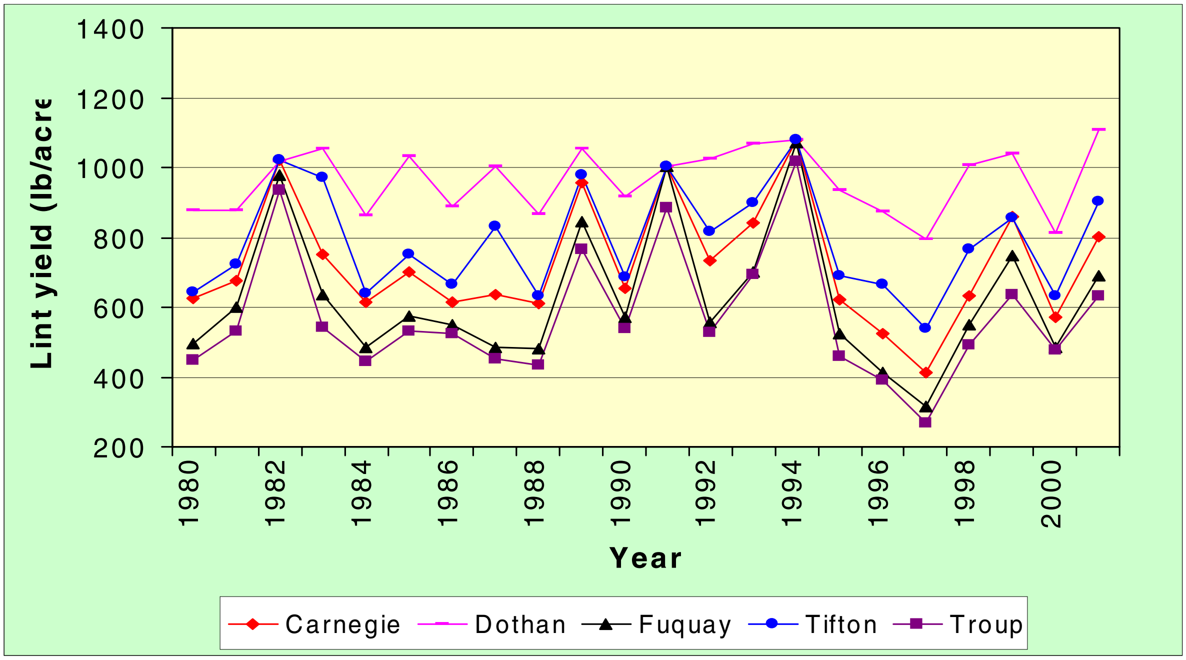

Figure 1. Yield for rainfed cotton for different soils.

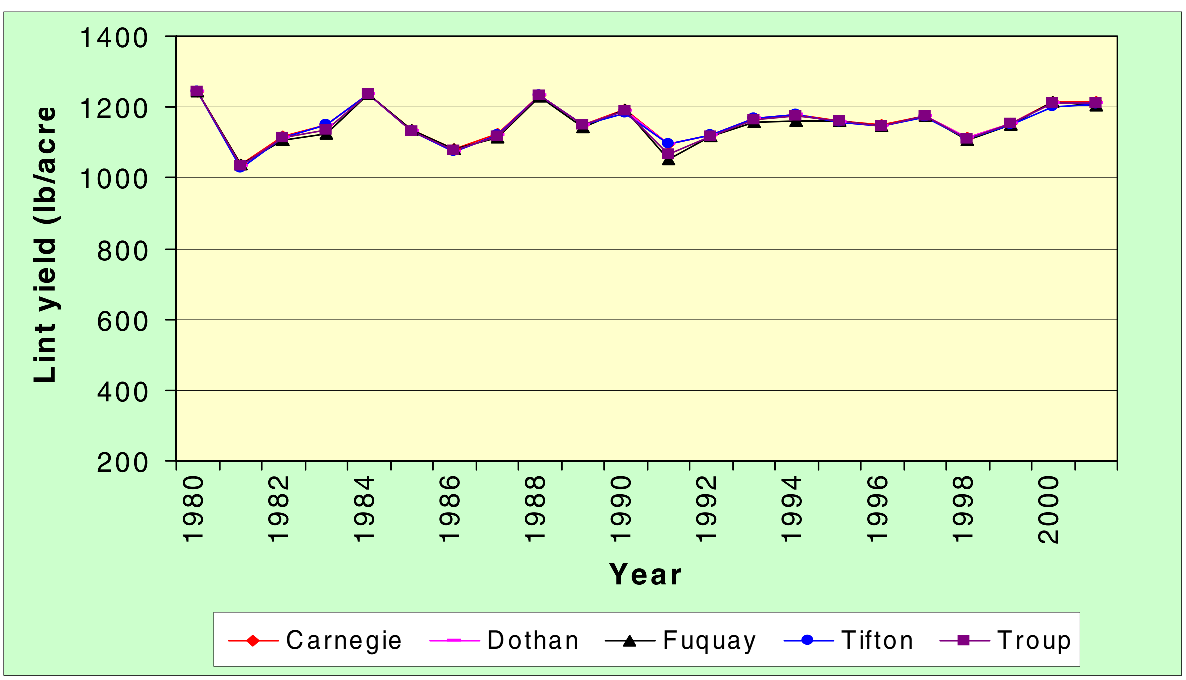

Figure 2. Yield for fully irrigated cotton for different soils.

Table 2. Average yield and water demand for irrigation for cotton (1980-2001).

	Fully Irrigated				Rainfed	
	Lint Yield		Irrigation		Lint Yield	
	mean	sd	mean	sd	mean	sd
	(lb/acre)		(inches)		(lb/acre)	
Carnegie	1160	53.6	17.4	5.4	723	169.7
Dothan	1152	53.6	6.5	4.5	964	89.3
Fuquay	1152	53.6	29.5	3.3	625	196.5
Tifton	1152	53.6	12.0	6.0	786	151.8
Troup	1152	53.6	28.5	3.2	572	187.5

The yield response to an increase in total irrigation for different soils is shown in Figure 3. Cotton yield showed a linear increase with an increase in total irrigation until maximum yield was reached under non-stress conditions. The Troup loamy sand and Fuquay sand, the soils with the highest hydraulic conductivity, showed the greatest range in yield response to an increase in total irrigation. For the Dothan loamy sand, there was little increase in yield with an increase in total irrigation.

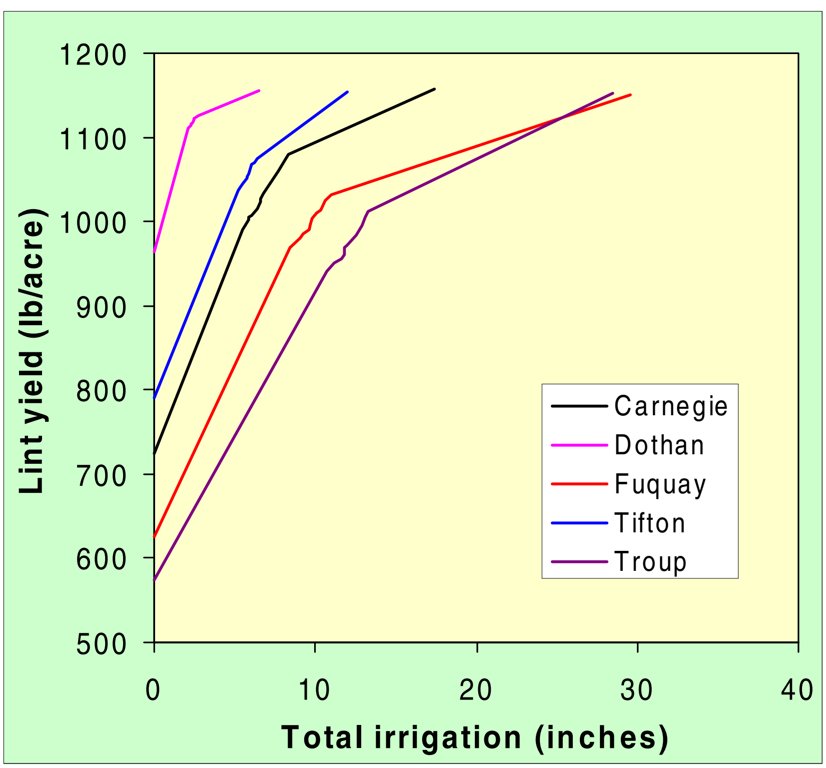

Figure 3. Yield versus total irrigation for different soils.

Conclusions

The EPIC model was used to evaluate crop yield response to irrigation for different soil and weather conditions. Yield predictions showed the highest variation for the rainfed conditions, while the annual yield variability was greatly reduced when irrigation was applied. Rainfed yield was lowest for the Troup loamy sand and was highest for the Dothan loamy sand. For maximum yields under non-stress conditions, the Fuquay sand had the highest irrigation demand while the Dothan loamy sand had the lowest irrigation demand. Cotton yield showed a linear increase with an increase in total irrigation until maximum yield was reached under non-stress conditions. The Troup loamy sand and Fuquay sand showed the greatest range in yield response to an increase in total irrigation. For the Dothan loamy sand, there was little increase in yield with an increase in total irrigation.

This study showed that the EPIC model can be a useful tool for determining water demand for irrigation at a farm level for different soil and weather conditions. With expected limited water availability for agriculture in the near future due to the increasing urban and industrial demands, EPIC can be used to determine minimum irrigation requirements for obtaining acceptable yield levels and to analyze the effects of limiting irrigation amounts on crop yield. Future efforts will focus on using the model for regional estimation of water use for irrigation in Georgia.

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