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A B S T R A C T

OPTIMAL ALLOCATION AND SCHEDULING OF IRRIGATION WATER FOR COTTON AND SOYBEANS

This study evaluated alternative irrigation scheduling strategies for cotton and soybean production on Sharkey clay soils in southeast Arkansas. Strategies were ranked on the basis of two basic criteria: expected net revenue and risk efficiency. Risk efficiency was defined for different risk preferences using stochastic dominance techniques. Preferred strategies for cotton employed tensiometer thresholds between -.45 atm and -.75 atm. Risk efficient soybean irrigation strategies varied with the degree of risk aversion--more risk averse decision makers prefer strategies with lower thresholds.

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Completion Report to the U.S. Department of the Interior, Washington, D.C., September, 1985.

Keywords -- Cotton/Soybeans/Irrigation Practices/Scheduling/Computer Model/Stochastic Model

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INTRODUCTION

The purpose of this study is to determine the optimal allocation and timing of irrigation water for soybeans and cotton for Southeast Arkansas. Optimality is first defined in terms of economic efficiency, then in terms of risk efficiency. Alternative solutions are compared for the two criteria and contrasted with engineering efficiency and yield maximization. Bio-physical, computer simulation models were used to evaluate the various irrigation scheduling strategies.

This study, although specific to Arkansas, addresses a problem that all farmers who use irrigation must consider. Inefficient allocation and timing of irrigation applications can prevent farmers from realizing the full potential of their irrigation investments. This can result in lower expected yields, increased production risks through variability in yields and lower farm incomes. Scheduling and efficient water use is also important given the rapid growth in irrigation in the state. From 1975 to 1980, the irrigated acreage in Arkansas increased by 50 percent. Three crops (rice, cotton and soybeans) accounted for 90 percent of the increase. In that time, soybean irrigated acreage increased by over 100 percent and in 1980, slightly under 20 percent of all soybean acreage was irrigated (USDA, 1983). Irrigation scheduling may have impacts at both the farm level and at the aggregate demand level as well. This study will focus on only the farm level inputs.

Inefficient allocation and timing of water applications is particularly relevant to Arkansas because the irregular rainfall patterns in this region complicate scheduling decisions. Arkansas farmers also have a tendency to rely on their experience and observations of the crop to schedule irrigations. Water applications made after the crop has incurred drought stress are not as effective as possible because yield loss has already occurred. The use of tensiometers and other soil moisture monitoring devices is the recommended practice, but only a small percentage of the farmers actually use any of these instruments.[1] Due to the uncertainty introduced by the irregular rainfall, farmers' attitudes toward risk must be considered. Efficient scheduling can reduce the impacts of weather uncertainty but perhaps only by adopting strategies with lower expected returns. However, some growers may prefer the variability in returns to the reduction in the expected return.

A. Purpose and Objectives

This study hopes to provide information on the efficient allocation and timing of irrigation water, thus encouraging farmers to adopt production practices which reduce risk, increase farm incomes and potentially decrease the agricultural water demand on the current base of irrigated acres.

The overall objectives of this paper are divided into three specific parts. They are: 1) to identify the yield changes under

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[1] Based on a 1983 survey of cotton growers participating in Bollworm Management Communities, only 25 percent of the cotton growers who irrigate use tensiometers.

selected conditions of various soybean and cotton irrigation schedules, soil types and varieties; 2) to evaluate the combinations of these alternative strategies with the criteria of economic efficiency and risk efficiency; and 3) to compare and to contrast the results using the alternative criteria of engineering efficiency and maximum yield. For the purpose of this paper, engineering efficiency is defined as the average physical product and is calculated as the total yield divided by the total amount of irrigation water applied to the crop. Economic efficiency is defined as the highest average net returns and risk efficiency is based upon utility maximization.

Risk efficiency is evaluated with stochastic dominance with respect to a function, SDWRF (Meyer, 1977) and results in efficient sets of strategies that are consistent with the risk preferences of specified groups of decision makers. Different irrigation scheduling strategies will be identified in this paper for four classes of decision makers with varying risk attitudes. These classes will include: 1) groups who are unwilling to bear risk; 2) groups who are willing to bear small amounts of risk; 3) groups who are risk neutral; and 4) groups who are willing to bear substantial risk to increase expected net returns.

B. Related Research or Activities

Efficient scheduling of water application allows the farmer to increase the intensity of land use, raises agricultural productivity and can lower per unit cost of production (Bajwa, et al., 1983). The farmer in humid regions, typically aided by specialists, estimates water requirements in advance of production and develops plans for an irrigation water supply system. This system represents a substantial long-term capital investment. Mederski and Jeffers (1972) point out that in the absence of irrigation, soil moisture levels or potentials, except following a rainfall, "are seldom high enough to ensure the optimum plant water potential required maximum yield."

There is substantial literature available to support the assertion that irrigation scheduling is critical to crop performance (Lambert et al., 1981; Hammond et al., 1981; Spooner et al., 1958). The assumptions made regarding the importance of the water supply to crops, the use of simulation models in place of field experiments and risk as related to irrigation are valid and well documented.

Musser and Tew (1984), in their article on the applications of simulation models, point out that use of bio-physical simulation models can be efficient and expedient alternatives to field experiments when evaluating certain production problems in agriculture, especially those that contain an element of risk. There have been many studies done in recent years that incorporate this methodology (Yaron and Dinar, 1982; Gilley et al., 1980; Yar, 1980; Feddes et al., 1978; and Mapp and Eidman, 1975; Boggess, et al., 1983; and Lynne et al., 1984).

In a study conducted at the University of New Mexico, Lansford et al. (1984) used two irrigation scheduling models to demonstrate the increases in yields and net return possible with irrigation scheduling. The models used were a dynamic programming model and a bio-physical simulation model. The profit maximizing, dynamic programming model considered price before making an irrigation application and then only added water when the value of the additional water exceeded the cost. The bio-physical model chose to irrigate when the soil moisture reached a predetermined level as defined by the percentage of the ratio between field capacity and permanent wilting point.

The results from Lansford's, this study showed that the dynamic programming model produced higher yields and net returns for each of the crops simulated (alfalfa, corn and sorghum). The net returns for sorghum were higher with the bio-physical model at the 40 percent soil moisture level, implying that sorghum can tolerate some drought stress during the growing season. In either case, yields and net returns were higher than those reported in the New Mexico State University crop budgets for typical farms. Risk efficiency was not considered in the study.

Uncertain weather patterns, seasonality of production and the nature of agricultural commodities make risk an inescapable feature of agricultural production. Farmers' attitudes toward risk affect their management and investment decisions on all levels. Management decisions ranging from what crop to plant to specific production practices are affected by producers' preferences or aversion to risk. Risk efficiency considers both the average net revenue and the variability in that net revenue which may occur through a series of growing seasons. It ranks alternative management strategies consistent with the willingness of the producers to bear risk.

Two recent studies incorporate risk efficiency and irrigation scheduling. Boggess et al. (1983) from Florida, demonstrated that the profit maximizing strategies were those that called for frequent applications at smaller rates and incomplete wetting of the soil profile. They also showed that when price variability was introduced, risk-averse decision makers chose to irrigate less frequently but at higher rates than that prescribed by the maximum net returns strategy. This demonstrates that risk preferences do affect management decisions.

Harris, Mapp and Stone (1983) used stochastic efficiency criteria and optimal control theory to develop irrigation strategies designed to reduce the water demand from the Oklahoma panhandle region of the Ogallalla aquifer. They found that for risk-averse decision makers, schedules that include irrigation during growth stage 4 (antithesis to physiological maturity) were dominant over the contemporary strategies based on calendar dates.

METHODS AND PROCEDURES

To research soybean and cotton growth and water response for Arkansas, two bio-physical crop growth simulation models were modified for this experiment. The crop growth models were used to simulate the performance of a series of irrigation strategies for both crops. From these simulations, several performance variables were monitored i.e. (yields, net returns, number of applications and total water applied) and probability distributions of net revenues were developed. Expected values for the performance variables were compared and the probability distributions were analyzed with Stochastic Dominance With Respect to a Function (Meyer, 1977; King and Robison, 1981; Cochran, et. al., 1984) to determine risk efficiency.

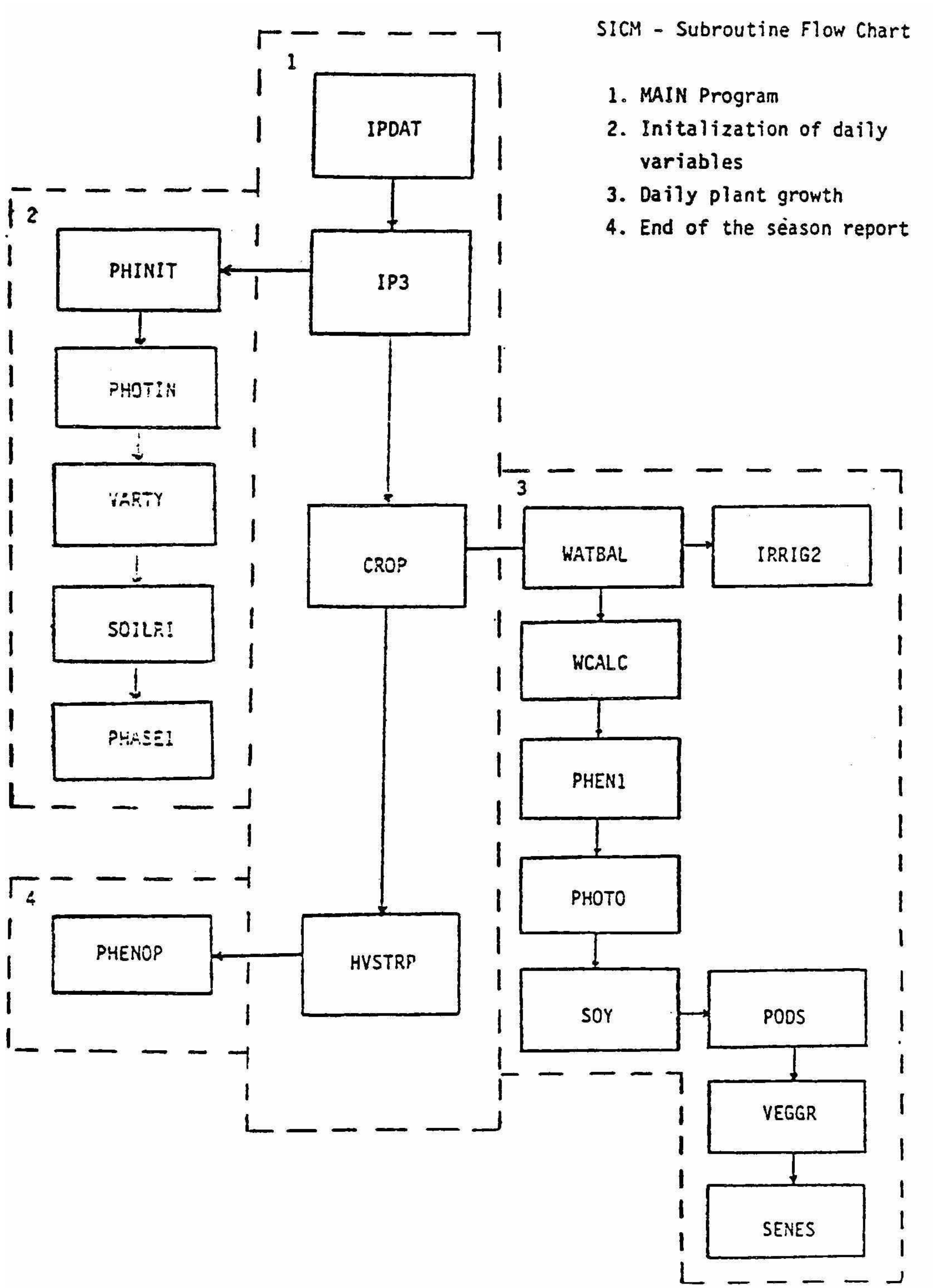
A. Soybean Model

Soybean Integrated Crop Management (SICM) was the model adapted for the soybean analysis. It was developed at the University of Florida, Gainesville, Florida by Wilkerson, et al. (1981). The development of the model was an interdisciplinary effort by the agricultural engineers, agronomists, entomologists and agricultural economists. The model contains components of crop, soil, insect, tactics (pesticide and irrigation applications) and economics. SICM is designed to study various soybean insect pest and irrigation management strategies during a season for systems consisting of different weather regimes soybean varieties, irrigation systems and insect infestations. The model is written in FORTRAN, using a modular subroutine structure.

SICM is broken into four main sections: 1) plant process growth, 2) soil moisture, 3) irrigation and 4) economic factors of seasonal soybean growth. A simple flowchart of the model is presented in Figure 1.

Each of the four main sections of SICM had to be modified to simulate soybean growth for Arkansas. The Florida weather data files were replaced by the Stoneville, Mississippi weather data. The Florida soil is sandy, therefore, the soil moisture section of SICM

FIGURE 1


SICM - Subroutine Flow Chart
1. MAIN Program
2. Initalization of daily variables
3. Daily plant growth
4. End of the season report
1
2
3
4
IPDAT
IP3
PHINIT
PHOTIN
VARTY
SOILRI
PHASE1
CROP
WATBAL
IRRIG2
WCALC
PHEN1
PHOTO
SOY
PODS
VEGGR
SENES
HVSTRP
PHENOP

was changed to represent more closely Arkansas' silty and clayey soils. The plant process growth section was modified to represent the Arkansas varieties of soybean and their phenological development. The economic calculations were changed to reflect those used in Arkansas. Lastly, the irrigation component was expanded to include the 37 proposed irrigation strategies.

The Florida weather files contain daily measurements for temperature, rainfall, pan-evaporation (the maximum level of evaporation), PAR (photosynthetically active radiation), times of sunrise and sunset and total solar radiation (langleys). They were replaced by 23 years of daily records from Stoneville, Mississippi for the years 1960 to 1982. Stoneville, Mississippi is located across the Mississippi River on Arkansas' southeastern border. This weather data file was selected because of the large number of data years available and because solar radiation and pan-evaporation was recorded, which had not been done in Arkansas. The Stoneville weather files contain the following entries: daily amounts of rainfall (cm), daily pan-evaporation, total daily solar radiation (langleys) and the daily maximum and minimum air temperatures (^{o}C). A procedure to convert daily temperature values to hourly values was developed to allow the model to approximate more closely actual weather conditions. This was done with a sine curve using the maximum and minimum values as anchors.

The soil water component has been changed to represent the Crowley soil conditions in the southern delta of Arkansas. The

Crowley soil is composed of a surface layer of silt loam about 37 centimeters deep over a thick layer of clay. The soil is subdivided into seven vertical zones, each one of which contains its own soil water and root length density. The water content of each zone varied between a lower and upper limit; these limits were changed to more closely approximate Arkansas soil conditions. The weighting factor (WR) which determines the new root growth distributions for each soil level was calculated in the subroutine SOILRI to more closely represent the Crowley soil. These data were determined from Scott et al. (1985).

The phenological subroutine PHEN1, where the ten plant growth stages are calculated, has been changed to represent the earlier harvest dates, different soybean varieties and shorter growing season in Arkansas as compared with Florida.

The production costs for this study were taken from the Arkansas Soybean Budgets. Both variable and fixed production costs were included. The variable costs for seasonal production and harvest are $93.60 per acre. These costs were converted from per bushel basis to a per acre basis as a simplification to reflect the fact that many of these activities are performed at the same level regardless of the yield expectations. The fixed costs, which included machinery and overhead, are $53.40 per acre. Therefore, the total production cost was estimated at $147.00 per acre in 1984 dollars. Irrigation costs were handled separately from these figures. The cost of irrigation was modified to represent a 300 acre center pivot system.

There are several assumptions relevant to both irrigation systems present in the calculations. The well depth for both systems is estimated to be 90 feet with 10 feet of draw down. These numbers represent the average depth and draw down of 60 wells in Arkansas County. The interest rate is set at 13 percent and the tax rate at one percent of the total investment. The straight line method is used to depreciate the machinery over its estimated life and an insurance rate of .6 percent of the equipment investment is assumed.

Irrigation costs were estimated on a variable per acre inch and fixed per acre basis. Minimal labor is all that is required to operate a center pivot. Based on Arkansas Soybean Budget estimates, 0.05 hours per acre inch is the amount of labor used and a wage rate of $4.50 per hour was assumed. The fixed irrigation costs were $47.67 per acre and the variable irrigation costs equaled $2.59 per acre inch.

The subroutine IRRIG2 is where the decision to irrigate was made and it was modified to include the 37 proposed irrigation scheduling strategies. The irrigation strategies used in this paper were developed by consulting agronomists and the soybean literature. The 37 irrigation strategies include applications by a mixture of growth stage information, tensiometer readings and the capacity of extractable water. Tensiometer strategies using bar readings were combinations of different thresholds values and three different reading depths of 15cm, 30 cm, and 60 cm. To distinguish the original Florida version of the SICM model from the version adapted to Arkansas conditions, we have designated the latter as ASICM.

B. Soybean Irrigation Strategies

Table 1 lists the irrigation strategies that are to be used in this paper. The strategies fall into five main categories: (a) non-irrigated; (b) static, tensiometer strategies; (c) dynamic tensiometer strategies; (d) static capacity of extractable water strategies; and (e) dynamic capacity of extractable water strategies. To make the irrigation strategy names in this paper understandable, the following code has been used:

1) All Static tensiometer strategies begin with the letter 'T' followed by the bar reading (i.e. -04 for -0.4bars) and then the depth in cm of the soil where the tensiometer is placed.
2) All the dynamic tensiometer strategies begin with 'R', the growth stage, followed by the weeks before R1 when irrigation water is first applied, lastly the threshold bar reading for irrigation after R1 is given (i.e. 05 for -0.5bars).
3) For the static capacity of extractable water approach the word 'Cap' begins each strategy name followed by the percent of water in the soil profile which triggers irrigation.
4) The dynamic capacity of extractable water strategies begin with 'Cap' also, followed by the percent of water which triggers irrigation until growth stage R2 and then the percent of water which triggers.

C. Cotton Model

A bio-physical, crop growth model for cotton, COTCROP, developed by Brown et al. was adapted to Arkansas conditions for this portion

Table 1: Soybean Irrigation Strategy Descriptions

Strategy Name	Description
Non-Irrig	Non-Irrigated soybeans
Tensiometer Strategies	
T-01-15	-0.1 bars placed at 15 cm
T-03-15	-0.3 bars placed at 15 cm
T-04-15	-0.4 bars placed at 15 cm
T-05-15	-0.5 bars placed at 15 cm
T-08-15	-0.8 bars placed at 15 cm
T-10-15	-1.0 bars placed at 15 cm
T-40-15	-4.0 bars placed at 15 cm
T-01-30	-0.1 bars placed at 30 cm
T-03-30	-0.3 bars placed at 30 cm
T-04-30	-0.4 bars placed at 30 cm
T-05-30	-0.5 bars placed at 30 cm
T-08-30	-0.8 bars placed at 30 cm
T-10-30	-1.0 bars placed at 30 cm
T-40-30	-4.0 bars placed at 30 cm
T-01-60	-0.1 bars placed at 60 cm
T-03-60	-0.3 bars placed at 60 cm
T-04-60	-0.4 bars placed at 60 cm
T-05-60	-0.5 bars placed at 60 cm
T-08-60	-0.8 bars placed at 60 cm
T-10-60	-1.0 bars placed at 60 cm
T-40-60	-4.0 bars placed at 60 cm
R1-00-05	one application at R1 and then -0.5 bars until R6
R1-01-05	one application one week before R1 and then -0.5 bars until R6
R1-02-05	one application two weeks before R1 and then -0.5 bars until R6
Capacity of Extractable Water Strategies	
Cap-10	water applied when RATIO = .10
Cap-20	water applied when RATIO = .20
Cap-25	water applied when RATIO = .25
Cap-30	water applied when RATIO = .30
Cap-40	water applied when RATIO = .40
Cap-50	water applied when RATIO = .50
Cap-60	water applied when RATIO = .60
Cap-70	water applied when RATIO = .70
Cap-80	water applied when RATIO = .80
Cap80-70	water applied at RATIO = .80 until R2 and then at RATIO = .70
Cap75-65	water applied at RATIO = .75 until R2 and then at RATIO = .65
Cap70-60	water applied at RATIO = .70 until R2 and then at RATIO = .60

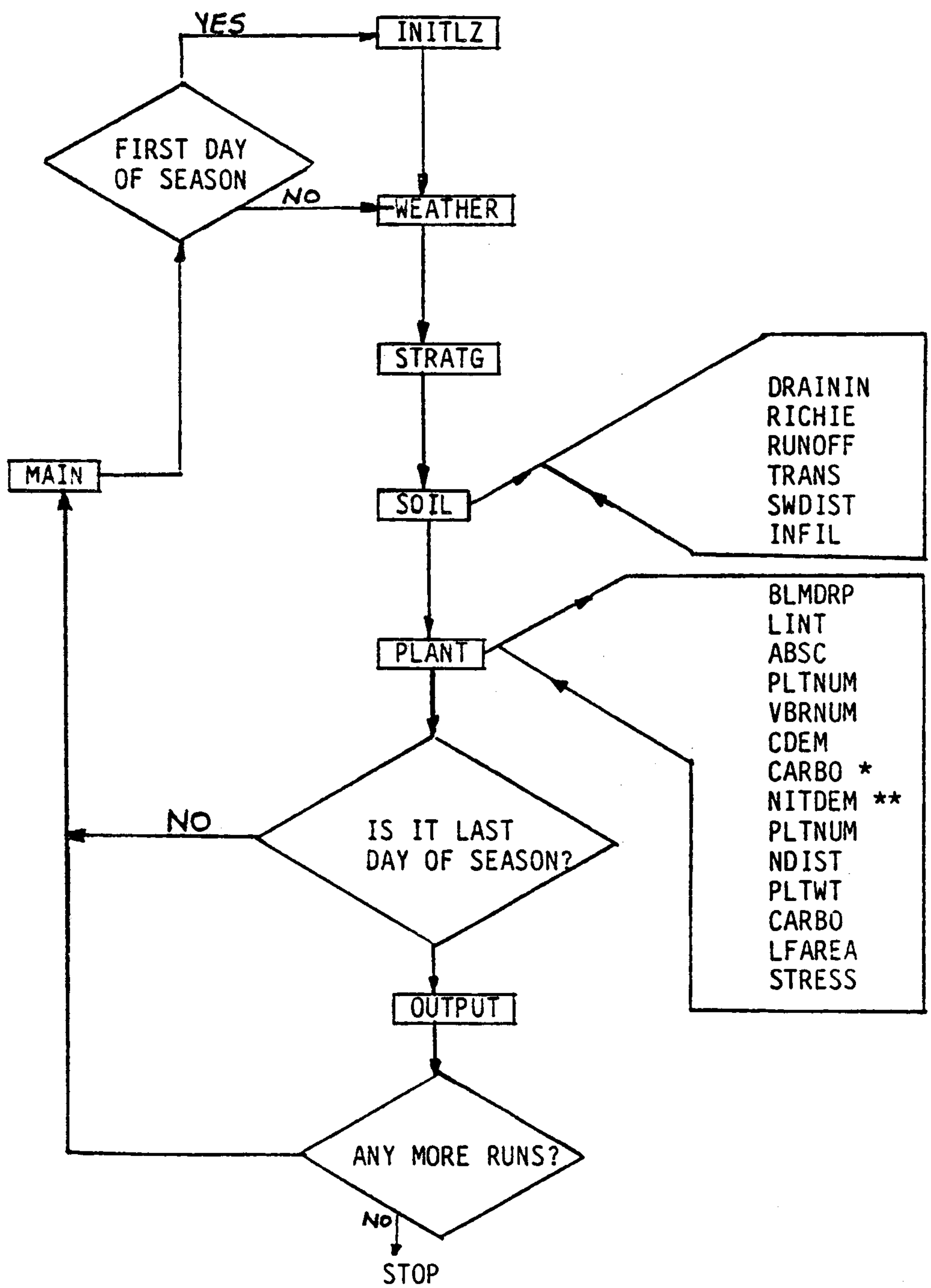
Ratio = Actual Water Storage/Potential Water Storage of the study. This model is written in FORTRAN. COTCROP calculates plant growth by simulating carbohydrate, nitrogen and water balances for the plant. Nitrogen and water balances are approximated for the soil root zone, specified by the user. Plant growth is a function not only of the three balances but of the weather factors of daily solar radiation (langleys), daily maximum and minimum temperatures (^{o}F), daily pan evaporation (inches) and daily rainfall (inches). Daily temperature values were converted to hourly values with a sine curve anchored by the maximum and minimum observations.

In COTCROP, the state of the crop is defined by vectors for each organ class of fruit, stems and leaves. In each vector there are elements which specify the number, weight and nitrogen content for plant organs of different ages. Leaf areas of different ages are also maintained. These variables are continuous but time and age are handled in a discrete manner in the model. The integration of the plant processes are managed by daily time steps. A simplified flowchart for COTCROP appears in Figure 2.

To designate the version of COTCROP which was adapted to southeast Arkansas conditions from the original, the label COTCROP-A was selected. Most of the changes involved resetting initialization values for user supplied variables. However, some structural changes to the program were implemented. COTCROP-A is divided into several modules. They are WEATHER, SOIL, PLANT, WORM, WEEVIL and SPRAY, which contain the scientific subroutines that implement the simulation. Other modules are: MAIN, which contains the main controlling program

FIGURE 2

FLOW CHART OF COTCROP
CYCLES ONCE PER DAY



* CYCLES UNTIL CARBOHYDRATE IS BALANCED
** CYCLES UNTIL NITROGEN IS BALANCED

and initialization subroutines; STRAG, which contains the predefined irrigation and pest control strategies; and OUTPUT, which prints the output tables.

The weather values used in the study simulations were actual daily records from Stoneville, across the Mississippi River, from Southeast Arkansas. These records were judged to be representative of southeastern Arkansas, which had only incomplete weather data available. Production and harvest cost data for this study have come primarily from the 1984 Arkansas Cotton Budgets published by the Cooperative Extension Service. These budget estimates are reported on a per acre basis and assess cotton production on sandy or silt loam soils in the South Delta region of Arkansas.

The information in the budgets is divided into pre-harvest and harvest variable costs and pre-harvest and harvest fixed costs. The variable irrigation costs are calculated on a per application and per acre inch basis to allow for comparisons between the irrigation strategies.

The calculations for irrigation costs are taken from a variety of sources including the University of Minnesota Agricultural Experiment Station third DISC report, the 1984 Arkansas Cotton Budgets and an American Association for Vocational Instructional Materials (AAVIM) publication.

There are several assumptions relevant to both irrigation systems present in the calculations. The well depth for both systems is estimated to be 90 feet with 10 feet of draw down. These numbers represent the average depth and draw down of 60 wells in Arkansas County. The interest rate is set at 13 percent and the tax rate at one percent of the total investment. The straight line method is used to depreciate the machinery over its estimated life and an insurance rate of .6 percent of the equipment investment is assumed.

The center pivot system represented in this study is a self-propelled unit with a diesel engine and turbine drive unit designed to irrigate 300 acres. The initial investment costs for the system are estimated at $5000 for the well, $8714 for the power unit, $8300 for the pump and gearhead and $57,000 for the distribution system.

There is a minimal amount of labor required to operate this system and based on the Arkansas Cotton Budget estimates, .05 hours per acre inch is the value used to calculate labor costs. A wage rate of $4.50 per hour is assumed.

The furrow irrigation system represented in this study uses gated pipe and is designed to irrigate 160 acres. The initial investment costs for the system are estimated at $5000 for the well, $5999 for the power unit, $8300 for the pump and gearhead and $17,600 for the distribution system.

The variable labor requirement for a furrow system is greater than for a center pivot system. The value used to calculate labor for this system is .54 hours per application. This value falls within the range suggested by the AAVIM publication and is taken from the Arkansas Cotton Budget estimates. Additional labor and tractor costs are the two elements of the fixed cost per application calculation. These elements reflect the costs that remain constant regardless of the number of applications or the amount applied.

In addition to costs and weather parameters, COTCROP-A requires input data in several other areas. Management practices such as planting and harvest dates, plant density, pesticide applications, irrigation schedules and fertilizer applications must be specified. COTCROP-A identifies emergence date rather than planting date and approximates upland varieties which mature and are harvested 150 days following emergence. For this study, pests were not considered in the simulations. The values used for the management variables are as follows: emergence date-May 5; plant density-40,0000 plants per acre; harvest date-October 2; and nitrogen fertilization-40 lbs. preplant, 30 lbs. at first square and 30 lbs. at first bloom.

D. Timing of Applications - Cotton Irrigation Strategies

The irrigation strategies evaluated in this study were developed with input from several agronomists and represent a wide variety of scheduling options. Calendar dates, growth stage information and tensiometer readings were used individually and in combination to create eight strategies for a center pivot system and ten strategies for a furrow system. The strategies based solely on calendar dates or tensiometer readings reflect some of the current field practices of Arkansas cotton producers. The strategies that incorporate growth stage information represent a future direction for irrigation scheduling. These strategies are more easily explained if viewed in two separate groups.

The first group of strategies are referred to as static because the water application decision rule does not change throughout the growing season. This group includes:

1. one irrigation three weeks after first bloom

2. tensiometer readings (one threshold level employed throughout the growing season, i.e. each threshold defines a distinct strategy)

-.45 atm	-.65 atm
-.50 atm	-.70 atm
-.55 atm	-.75 atm
-.60 atm	

The recommended practice is to have applications occurring at -.55 atm.

The second group of strategies are considered dynamic because the water applications are based on tensiometer readings and growth stage information, thus implying changes in the decision rule as the growing season progresses. This group includes:

1. -.3 atm to -.45 atm from first square to eight weeks past first bloom.

2. -.3 atm to -.45 atm from first square to six weeks past first bloom, followed by -.46 atm to -.55 atm during the six to eight week period past first bloom

3. -.3 atm to -.45 atm from first square to three weeks past first bloom, followed by -.46 atm to -.55 atm during the four to eight week period past first bloom.

The depth of the tensiometer is important in measuring the soil moisture. A tensiometer depth of 12 inches (30 cm) is the common field practice.

E. <u>Amount of Water Applied - Cotton Irrigation Strategies</u>

These strategies were simulated for a center pivot irrigation system and a furrow irrigation system. Gated pipe was used in the furrow system. The center pivot system applied three quarters of an inch of water at each application, while the furrow system applied two inches of water on each application. The simulation model included an efficiency factor for each system. The center pivot system was assumed to be 90 percent efficient and the furrow system was assumed to be 60 percent efficient. These efficiency values represent the percentage of applied water that is actually available for plant use. Yield was also estimated with no water applications to demonstrate the increase in yields possible with irrigation (see Table 2 for strategy names).

PRINCIPAL FINDINGS AND THEIR SIGNIFICANCE

A. Soybean Results

All 37 of the irrigation strategies were simulated with the center pivot irrigation system. The Arkansas version of SICM used 23 years of weather data from 1960 to 1982. The Forrest variety of soybean was simulated and ASICM calculated yields, net revenue and irrigation amounts for each of the 23 years. The amount of water applied for all irrigation strategies was one acre inch.

The results for three of the four criteria are presented in Table 3. It can be seen that the strategies which are ranked highest for economic efficiency are T-04-15 and Cap75-65. The strategies that maximized expected yields are T-03-15 and T-04-15.

Expected yields decreased significantly when evaluating irrigation efficieny (average yield per average inches of water applied). T-40-30 resulted in the smallest use of water per acre when using a

TABLE 2

Strategy Cotton Irrigation Descriptions*

Center Pivot

CALCP	= one irrigation 3 weeks after first bloom
TENSCP45	= -.45 atm from first square to 8 weeks past first bloom
TENSCP50	= -.50 atm from first square to 8 weeks past first bloom
TENSCP55	= -.55 atm from first square to 8 weeks past first bloom
TENSCP60	= -.60 atm from first square to 8 weeks past first bloom
TENSCP65	= -.65 atm from first square to 8 weeks past first bloom
DYNCP1	= -.3 atm to -.45 atm from first square to 8 weeks past first bloom
DYNCP2	= -.3 atm to -.45 atm from first square to 6 weeks past first bloom, followed by -.46 atm to -.55 atm during the 6 to 8 week period past first bloom
DYNCP3	= -.3 atm to -.45 atm from first square to 3 weeks past first bloom, followed by -.46 atm to -.55 atm during the 4 to 8 week period past first bloom
NOIRR	= no irrigation

Furrow System

CALF	= one application 3 weeks past first bloom
TENSF45	= -.45 atm from first square to 8 weeks past first bloom
TENSF50	= -.50 atm from first square to 8 weeks past first bloom
TENSF55	= -.55 atm from first square to 8 weeks past first bloom
TENSF60	= -.60 atm from first square to 8 weeks past first bloom
TENSF65	= -.65 atm from first square to 8 weeks past first bloom

TABLE 2 Continued

TENSF70	=	-.70 atm from first square to 8 weeks past first bloom**
TENSF75	=	-.75 atm from first square to 8 weeks past first bloom**
DYNF1	=	-.3 atm to -.45 atm from first square to 8 weeks past first bloom
DYNF2	=	-.3 atm to -.45 atm from first square to 6 weeks past first bloom, followed by -.46 atm to -.55 atm during the 6 to 8 week period past first bloom
DYNF3	=	-.3 atm to -.45 atm from first square to 3 weeks past first bloom, followed by -.46 atm to -.55 atm during the 4 to 8 week period past first bloom
NOIRR	=	no irrigation
* atm	=	atmospheres of pressure; 1 atm = 1.017 bars on a tensiometer

**These strategies do not appear in the group of center pivot strategies because preliminary results demonstrated that the center pivot strategies with thresholds higher than -.65 atm were in Stage III of the production function, indicating an irrational range of input use.

Table 3

ASICM Model Output of Soybean Irrigation Strategies

Strategy	Average Yield Bushels	Average Net Returns in Dollars	Std. Dev. in Net Returns	Average Water Applied in inches	Irrigation Efficiency bu/in
Non-Irrig	27.29	44.06	90.41	0.0	0.0
T-01-05	62.78	180.36	31.64	24.9	2.5
T-03-15	63.60	198.08	30.91	20.3	3.1
T-04-15	63.59	211.97	29.85	14.9	4.3
T-05-15	62.35	210.04	32.03	12.3	5.1
T-08-15	60.14	202.00	45.98	9.4	6.4
T-10-15	59.03	196.77	56.92	8.4	7.0
T-40-15	46.26	119.61	103.19	3.7	12.5
T-01-30	63.17	184.37	31.38	24.4	2.6
T-03-30	62.17	210.79	34.16	11.5	5.4
T-04-30	61.65	211.86	39.29	9.7	6.4
T-05-30	59.41	199.57	55.35	8.4	7.1
T-08-30	54.98	174.06	75.64	6.2	10.3
T-10-30	52.75	160.71	84.43	5.4	9.8
T-40-30	39.12	77.58	110.67	2.2	17.8
T-01-60	62.47	191.37	28.20	19.8	3.2
T-03-60	61.88	195.51	32.31	16.6	3.7
T-04-60	62.22	198.52	37.82	16.3	3.8
T-05-60	60.14	188.00	48.02	14.8	4.1
T-08-60	57.48	174.50	68.00	12.8	4.5
T-10-60	56.40	169.69	80.11	11.7	4.8
T-40-60	44.59	106.60	124.05	5.8	7.7
R1-00-05	59.97	189.21	47.92	13.9	4.3
R1-01-05	57.41	189.10	54.91	7.0	8.2
R1-02-05	56.94	184.84	60.09	7.4	7.7
Cap-10	27.29	44.06	90.41	0.0	0.0
Cap-20	29.25	50.87	92.94	0.3	112.50
Cap-25	31.56	55.76	92.09	0.6	51.74
Cap-30	35.85	71.69	100.26	1.2	28.45
Cap-40	42.86	101.74	121.70	3.0	14.29
Cap-50	49.91	141.17	109.20	5.2	9.60
Cap-60	57.51	186.48	63.86	8.3	6.93
Cap-70	62.73	208.88	32.74	13.7	4.58
Cap-80	63.05	198.45	32.50	18.6	3.39
Cap80-70	62.88	205.84	36.04	15.3	4.11
Cap75-65	62.58	211.50	31.20	12.3	5.09
Cap70-60	61.16	207.57	29.32	10.0	6.12

tensiometer. T-40-30 had an efficient value of 17.78 bushels per inch of water applied. Strategy T-40-30 allowed the tensiometer to reach -4.0 bars before any irrigation water was applied. T-40-30 used an average of 2.2 inches of irrigation water per season, resulting in an average yield of 39.12 bushels per acre and an average profit of $77.58 per acre. Cap-20 had the lowest yield of 29.3 bushels per acre while having the highest irrigation efficiency compared with all other capacity strategies.

Statistical Testing

The Duncan Multiple Range test was calculated for the seven preferred strategies listed in Table 3 (T-05-30, R1-02-05, Cap75-65, T-04-15, T-05-15, T-03-30, T-04-30, T-05-30). The test indicated that none of the expected net returns were significantly different at an α = .05. One explanation for this outcome is that all of the seven preferred strategies are basically variations of the same irrigation technique, which is irrigation applied by the tensiometer placed in the top layer (37 cm) of soil when the tensiometer readings are between -.3 to -.5 bars. Also, the slope of the water retention curve is low in this region.

The Duncan Multiple Range test was also calculated for the complete set of 37 irrigation strategies (Table 4). Stochastic dominance is not based on expected net revenue calculations but on expected utility which reflects the entire cumulative distribution function. There are nine groups of strategies with significantly different expected net revenues. The group A, which includes the seven

Table 4

Duncan Multiple Range Test For Differences in Mean Net Revenues: Soybean Irrigation Strategies

Strategy Name	Mean Net Revenue	Duncan Grouping[1]					
	Dollars						
T-04-15	211.97	A					
T-04-30	211.86	A					
Cap75-65	211.55	A					
T-03-30	210.79	A					
T-03-15	210.04	A	B				
Cap-70	208.88	A	B				
Cap70-60	207.57	A	B				
Cap80-70	205.84	A	B	C			
T-08-15	202.01	A	B	C			
T-05-30	199.57	A	B	C			
T-04-60	198.52	A	B	C			
Cap-80	198.45	A	B	C			
T-03-15	198.08	A	B	C			
T-10-15	196.77	A	B	C	D		
T-03-60	195.51	A	B	C	D		
T-01-60	191.37	A	B	C	D		
R1-00-05	189.21	A	B	C	D		
R1-01-05	189.10	A	B	C	D		
T-05-60	188.00	A	B	C	D		
Cap-60	186.48	A	B	C	D		
R1-02-05	184.84	A	B	C	D		
T-01-60	184.37	A	B	C	D		
T-01-15	180.36	A	B	C	D		
T-08-60	174.51		B	C	D	E	
T-08-30	174.06		B	C	D	E	
T-10-60	169.69			C	D	E	
T-10-30	160.71				D	E	
Cap-50	141.17					E	F
T-40-15	119.45	G					F
T-40-60	106.60	G	H				F
Cap-40	101.74	G	H				
T-40-60	77.58		H	I			
Cap-30	71.71		H	I			
Cap-25	55.76			I			
Cap-20	50.87			I			
Cap-10	44.06			I			
Non-Irrig	44.06			I			

[1](Means with the same letter are not significantly different; $\alpha = .05$)

strategies preferred by all decision makers from risk-preferring to strongly risk-averse groups, also includes 16 other irrigation strategies.

The Duncan Multiple Range test can only give a rough estimate of the significance when applying stochastic dominance. Differences in mean yields are neither necessary nor sufficient conditions for the differences in expected utility. However, to-date there is no procedure to statistically test the significance of results when using risk intervals with stochastic dominance.

Another note of caution must be exercised, Duncan's Multiple Range Test assumes that normal distributions are being examined. An SAS Univariate Normal test was used to check if each irrigation strategy's yearly net return followed a normal distribution at α =.05. Only seven of the 37 irrigation strategies fit the normal curve. They were: Cap-80, T-01-15, T-03-15, T-08-15, T-03-30, T-03-60 and R1-01-05. Only T-03-15 and T-03-30 were included in one of the four efficient sets. Yet, for lack of a better test at this time, the Duncan Multiple Range test shows that all seven of the efficient strategies have no statistical difference in mean net revenue at α =.05.

Risk Analysis

Risk efficiency can only be defined for specified ranges of risk preferences. This study has used four different sets of preferences, each representing a different class of decision makers. By comparing the efficient sets identified for each set of preferences, inferences can be made as to the influence that risk preferences can have on the relative rankings of the strategies. The preferences and the efficient sets derived with stochastic dominance with respect to a function are displayed in Table 5. The preferences are expressed in intervals with bounds measured with Pratt risk-aversion coefficients. The outcome variables were scaled to reflect the average soybean component of farms in southeast Arkansas. This was accomplished by multiplying the per acre returns by 300.

Table 5

Preference Intervals Used to Define Groups of Decision Makers

Group of Decision Makers	Pratt/Arrow Risk Coefficient[1]
risk preferring	-.0008 to -.0001
approaching risk neutral	-.0001 to .0001
slightly risk averse	.0001 to .0004
strongly risk averse	.0004 to .001

[1]The intervals are defined based upon empirical work (Cochran, Robison and Lodwick).

The efficient set identified for the group of risk-preferring decision makers contained strategies that used a tensiometer placed at 30 cm in the soil. T-05-30 and R1-02-05 were the two preferred strategies, both have large ranges in net returns (Table 6). Strategies T-05-30 and R1-02-05 have slightly lower average net returns than the profit or yield maximizing strategies of T-04-15 and T-03-15, respectively, although the differences were non-significant.

Table 6

Risk Efficient Soybean Irrigation Strategies for Different Groups of Decision Makers

	Average Net Returns	Minimum Net Returns[1]	Maximum Net Returns	Average Water Applied (in)
Risk Preferring (-.0008 to -.0001)				
T-05-30	199.57	38.91	278.00	8.4
R1-02-05	184.84	38.91	275.75	7.4
Approaching Risk Neutral (-.0001 to .0001)				
Cap75-65	211.55	146.14	251.93	12.3
T-04-15	211.97	152.10	252.22	14.9
T-05-15	210.04	153.75	259.13	12.3
T-03-30	210.79	136.72	268.53	11.5
T-04-30	211.86	88.70	275.82	9.7
T-05-30	199.57	38.91	278.00	8.4
Slightly Risk Averse (.0001 to .0004)				
T-04-15	211.97	152.10	252.22	14.9
T-05-15	210.04	153.75	259.13	12.3
Strongly Risk Averse (.0004 to .001)				
T-04-15	211.97	152.10	252.22	14.9
T-05-15	210.04	153.75	259.13	12.3

[1]All of the minimum returns occurred in the extremely dry year 1980.

The group of decision makers defined as approaching risk neutral had an efficient set of six irrigation strategies. The group included one dynamic capacity strategy, Cap75-65, two static strategies where the tensiometer was placed at 15 cm, T-04-15 and T-05-15 and three static strategies, T-03-30, T-04-30 and T-05-30, where the tensiometer was placed at 30 cm. Risk-neutral decision makers want the highest return for their dollars invested and as the stochastic dominance model predicted, these six strategies produce the highest returns over the 23 years of simulation.

The slightly risk-averse and strongly risk-averse decision makers preferred the same two strategies, T-04-15 and T-05-15 (Table 6). Strategy T-05-15 had an average net return of $210 per acre and a standard deviation of $32.03 per acre. Strategy T-04-15 had an average net return of $211.97 per acre and a standard deviation of $29.85 per acre.

Risk-averse decision makers put more emphasis on the low income years and, hence, are interested in the poorest outcomes or net returns in this study. For example, strategies T-04-15 and T-05-15 each have the highest incomes in 1980 of $152.10 and $153.75, respectively, over all of the other irrigation strategies in the group of seven picked by all decision makers. This performance in the worst income year resulted in these strategies being risk efficient for these decision makers.

The results of this analysis went as expected at the beginning of this study. It was assumed at the start of this paper that irrigation water could be used as a risk-reducing input, therefore, decision makers would choose to apply more water as they become more risk averse. This condition was observed by the results. The data in Table 6 summarizes the four groups of decision makers and their resulting efficient sets.

The risk-neutral decision makers favored an average of three inches additional irrigation water than the risk-preferring decision makers. The risk-averse decision makers favored an average of five additional inches of irrigation water per season over the risk-preferring group. The results, therefore, give validity to the hypothesis that irrigation is an important risk-reducing input to Arkansas soybean farmers in the short run. Further discussion of the results and ASICM may be found in Prickett (1985).

B. Cotton Results

Each of the 12 strategies was simulated with the center pivot and furrow irrigation systems. The model incorporated 23 years of weather data, from 1960 through 1982. Based on the assumptions that farmers are committed to an irrigation system already in place and there are no differences between systems if used properly, no comparisons of the strategies were made across the two systems. The analysis begins with the center pivot system.

Center Pivot System

Profit maximization and yield maximization were used in the evaluation of economic efficiency. The profit maximizing strategy on the center pivot system came from the dynamic group of strategies that combined growth stage information with tensiometer readings.

DYNCP2 resulted in an average yield of 829.5 pounds of lint per acre with average net returns of $478.48 per acre. The net returns are only above irrigation costs. This strategy called for an average of 5.9 inches of water to be applied each growing season (Table 7). There is a major improvement in both expected net returns and yields associated with the tensiometer strategies. Net returns are increased on average by about $130 per acre over the non-irrigated strategy. CALCP did result in a higher mean yield, but with a cotton price of 65¢ per pound, the expected net returns were actually lower than the non-irrigated strategy. These results support the notion that the use of tensiometers is economical. Statistical tests based on Duncan's Multiple Range test indicate that there was not much difference in expected yields and net returns between any of the tensiometer strategies.

The yield maximizing strategy for the center pivot system was also DYNCP2. With an average yield of 829.5 pounds of lint per acre, this strategy produced approximately 1.9 pounds per acre more than TENSCP50, the next highest strategy, and two to four pounds per acre more than any of the strategies based solely on tensiometer readings (Table 7).

In terms of irrigation efficiency (average yield/average inches of water applied), TENSCP65 resulted in the most efficient use of irrigation water for the center pivot system. With an efficiency value of 161.24 pounds of lint per inch of water applied, TENSCP65 allowed the tensiometer reading to reach -.65 atm before applying

Table 7

COTCROP-A Model Results for Cotton Irrigation Strategies: Center Pivot System

CENTER PIVOT STRATEGIES	AVERAGE YIELD LINT[1,2]	AVERAGE NET RETURNS IN DOLLARS [1,2,3]	AVERAGE WATER IN INCHES	IRRIGATION EFFICIENCY
CALCP	590.5 (8) b	336.83 (8) b	.8	
TENSCP45	826.9 (4) a	476.33 (5) a	6.1	135.56 (7)
TENSCP50	827.8 (2) a	477.56 (2) a	5.9	140.30 (6)
TENSCP55	825.6 (5) a	476.77 (4) a	5.6	147.42 (3)
TENSCP60	823.4 (6) a	476.00 (6) a	5.3	155.35 (2)
TENSCP65	822.3 (7) a	475.95 (7) a	5.1	161.24 (1)
DYNCP1	same as TENSCP45			
DYNCP2	829.5 (1) a	478.48 (1) a	5.9	140.59 (5)
DYNCP3	827.3 (3) a	477.35 (3) a	5.8	142.64 (4)
NOIRR	575.0 (9) b	345.75 (9) b	0.0	-------

[1] numbers in parenthesis represent rank from high to low

[2] Duncan's multiple range test was used to determine differences between yield and net returns. Means within groups identified by "a" and "b" are not statistically significantly different at an $\alpha = 0.05$.

[3] Net returns are above irrigation costs only.

water. With this strategy, an average of 5.1 inches of water was applied resulting in an average yield of 822.3 pounds per acre. The profit and yield maximizing strategy, DYNCP2, called for an average of 5.9 inches of water to produce an average yield of 829.5 pounds per acre but produced only 140.3 pounds per inch of irrigation water. The calculation for irrigation efficiency is the same as that for Average Physical Product. TENSCP65, with an average of 5.1 inches of water applied, approximates the beginning of Stage II of production. At this point, Average Physical Product is maximized and is equal to Marginal Physical Product (Table 7). Stochastic dominance with respect to a function was used to evaluate the strategies for risk efficiency.

Risk-efficient strategies were determined for four groups of decision makers. All outcomes variables were scaled to approximate the average cotton component of farm operations in southeast Arkansas. This was achieved by multiplying the per acre returns by 300. For this study, the preference intervals defining the decision groups are as follows:

risk preferring	-.0008 to -.0001
approaching risk neutral	-.0001 to .0001
slightly risk averse	.0001 to .0004
strongly risk averse	.0004 to .001

The most efficient strategy for risk-preferring decision makers was TENSCP50, followed by DYNCP2, TENSCP60, TENSCP55 and DYNCP3 (Table 8). DYNCP2, the profit and yield maximizing strategy, was

Table 8

Risk Efficiency Rankings for Cotton Irrigation Strategies:
Center Pivot System

	RANK	AVERAGE NET RETURNS	MINIMUM NET RETURNS	MAXIMUM NET RETURNS
RISK PREFERRING (-.0008 to -.0001)				
TENSCP50	1	477.56	177.01	766.35
DYNCP2	2	478.48	178.26	756.97
TENSCP60	3	496.00	195.89	754.89
TENSCP55	4	476.77	195.89	748.67
DYNCP3	5	477.35	178.26	740.05
APPROACHING RISK NEUTRAL (-.0001 to .0001)				
DYNCP2	1	478.48	178.26	756.97
TENSCP50	1	477.56	177.01	766.35
DYNCP3	1	477.35	178.26	740.05
TENSCP55	1	476.77	195.89	748.67
TENSPC60	1	476.00	195.89	754.89
TENSPC65	1	475.95	195.89	723.21
SLIGHTLY RISK AVERSE (.0001 to .0004)				
TENSPC65	1	475.95	195.89	723.21
TENSCP60	2	476.00	195.89	754.89
TENSCP55	3	476.77	195.89	748.67
DYNCP3	4	477.35	178.26	740.05
DYNCP2		478.48	178.26	756.97
STRONGLY RISK AVERSE (.0004 to .001)				
TENSCP65	1	475.95	195.89	723.21
TENSCP60	2	476.00	195.89	754.89
TENSCP55	3	776.33	178.26	734.48
DYNCP3	4	477.35	178.26	740.05
DYNCP2		478.48	178.26	756.97

determined to be not as risk efficient as TENSCP50 for risk-preferring decision makers. This was expected since risk-preferring farmers place more emphasis on the probability of high net returns than they do on low net returns. The highest net return for TENSCP50 was $10 an acre greater than that for DYNCP2.

The group of decision makers, defined as approaching risk neutral, had six strategies which were risk efficient. DYNCP2, TENSCP50, DYNCP3, TENSCP55, TENSCP60 and TENSCP65 all appear in the efficient set. The size of this efficient set reflects the fact that the performance of these strategies were very similar due to the retention characteristics of the soil. The Duncan Multiple Range test indicated that none of the expected yields or net returns of the tensiometer strategies were statistically significantly different at $\alpha = 0.05$.

The rankings of the top strategies for the slightly risk-averse and strongly risk-averse groups of decision makers were identical. The preferred strategy was TENSCP65, followed by TENSCP60, TENSCP5, DYNCP3 and DYNCP2. It appears that at the cotton price of 65¢ per pound, the higher thresholds maximize utility. Due to the inability of stochastic dominance techniques to test for statistical differences in expected utility and strong similarities in the probability distributions, caution must be exercised before the conclusion that irrigation is not a risk-reducing input is reached.

TENSCP50 produced the second highest average net returns and average yield but was less irrigation efficient than DYNCP2 with the same amount of water applied. This demonstrates the importance of timing water applications with growth stage information to insure maximum output for each unit of water applied.

The two groups of risk-averse decision makers showed no preference between TENSCP50 and DYNCP3 once DYNCP2 was eliminated from the efficient set. DYNCP3 called for slightly less water applied and resulted in only 1/2 pound of lint less in average yield and only 21 cents less in average net returns. It was slightly more irrigation efficient producing 142.63 pounds per inch of water, whereas TENSCP50 produced 140.30 pounds per inch of water. It is reasonable for the strongly risk-averse decision makers to be ambiguous between these strategies since they are very similar in nature. TENSCP50 called for a threshold of -.50 atm throughout the growing season, while DYNCP3 maintained a -.45 atm threshold until three weeks past first bloom, then went to a -.55 atm threshold through four to eight weeks past first bloom. Given that the difference in average water applied between the two strategies is only .10 of an inch over 23 years, it is possible that the preference intervals are not sensitive enough to pick up such a negligible difference.

Furrow System

The profit maximizing strategy for the furrow irrigation system came from the group of strategies based solely on tensiometer readings. TENSF70 allowed the tensiometer reading to reach -.70 atm before adding water. This resulted in an average yield of 809.0 pounds per acre and average net returns of $464.53 per acre. This strategy called for an average of 7.8 inches of water to be applied each growing season (Table 9).

A similar pattern as found with the center pivot results surfaced in the analysis of the furrow system. The Duncan Multiple Range test failed to uncover any significant differences between the expected yields and net returns for any of the tensiometer strategies. However, there was a significant difference between the average net returns for that group and the non-irrigated and calendar strategies. Expected net returns were increased by more than $80 per acre by the use of tensiometers. In this case, the calendar strategy had both a higher expected net return and yield than the non-irrigated strategy. The similarities in the results for the tensiometer strategies can likely be attributable to the moisture retention characteristics of the soil examined.

The yield maximizing strategy for the furrow system also came from the group of strategies based on tensiometer readings. TENSF60 allowed the tensiometer reading to reach -.60 atm before applying water and this resulted in the maximum average yield of 812.1 pounds per acre. TENSF60 produced approximately 3.1 pounds per acre more than the profit maximizing strategy and applied an average of 1.1 inches of water more per season than the profit maximizing strategy (Table 9).

In terms of irrigation efficiency, TENSF70, the profit maximizing strategy, resulted in the most efficient use of irrigation water on the furrow system. With an average yield of 809.0 pounds per acre and

Table 9

COTCROP-A Model Results for Cotton Irrigation Strategies:
Furrow System

FURROW SYSTEM STRATEGIES	AVERAGE YIELD # LINT[1,2]		AVERAGE NET RETURNS IN DOLLARS[1,2,3]		AVERAGE WATER IN INCHES	IRRIGATION EFFICIENCY
CALF	621.4 (10)	b	367.90 (10)	b	2.0	310.7
TENSF45	794.6 (9)	a	445.09 (9)	a	10.2	77.90
TENSF50	803.8 (5)	a	453.02 (6)	a	9.7	82.86
TENSF55	808.6 (4)	a	457.61 (4)	a	9.4	86.02
TENSF60	812.1 (1)	a	462.13 (3)	a	8.9	91.24
TENSF65	810.8 (2)	a	462.73 (2)	a	8.5	95.38
TENSF70	809.0 (3)	a	464.53 (1)	a	7.8	103.71
TENSF75	798.3 (7)	a	457.61 (4)	a	7.8	102.35
DYNF1	same as TENSF45					
DYNF2	794.8 (8)	a	446.01 (8)	a	5.9	79.48
DYNF3	799.3 (6)	a	450.10 (7)	a	9.7	82.40
NOIRR	575.0 (11)	b	345.75 (11)	b	0.0	-----

1 Numbers in parenthesis represent rank from high to low.

2 Duncan's multiple range test was used to determine differences between yield and net returns. Means within groups identified by "a" and "b" are not statistically significantly different at $\alpha = 0.05$.

3 Net returns are above irrigation costs only.

an average of 7.8 inches of water applied per year, TENSF70 produced an average of 103.71 pounds per inch of water over the 23 years of weather data. Although TENSF60, the yield maximizing strategy, applied more water, it only produced 91.24 pounds per inch of water. This demonstrates the economic principle of diminishing marginal returns. At the point where 7.8 inches of water was applied, the farmer realized maximum output per unit of variable input. After that point, although total yield continued to increase, the returns to each additional unit of water decreased (Table 9). At the maximum yield of 812.1 pounds per acre, 8.9 inches of water represents the maximum amount of water that can be applied without decreasing yield. The results from the other strategies bears this out. TENSF55 applied an average of 9.4 inches of water for an average yield of 808.6 pounds per acre. TENSF45 applied 10.2 inches and produced an average yield of 794.6 pounds per acre.

Risk efficient strategies were determined for the four groups of decision makers (Table 10). Once again, different rankings of strategies were produced for the different decision makers. The risk-preferring group ranked DYNF2 as the strategy which maximized utility. The slightly risk-averse and strongly risk-averse groups preferred TENSF75. Of the entire set of tensiometer strategies, only TENSF45 could be rejected as inefficient for the risk-neutral group. The inferiority of the calendar and non-irrigated strategies is once again apparent. It is surprising, though, to note that as risk aversion was increased, strategies which apply less water were preferred.

Table 10

Risk Efficiency Rankings for Cotton Irrigation Strategies:
Furrow System

	RANK	AVERAGE NET RETURNS	MINIMUM NET RETURNS	MAXIMUM NET RETURNS
RISK PREFERRING (-.0008 to -.0001)				
DYNF2	1	466.01	184.73	731.44
TENSF45	2	455.09	184.73	727.91
DYNF3	2	450.10	184.73	727.00
TENSF50	4	453.02	181.89	722.32
TENSF55	5	457.61	197.92	718.15
TENSF75	5	457.61	212.89	718.85
APPROACHING RISK NEUTRAL (-.0001 to .0001)				
DYNF2	1	466.01	184.73	731.44
DYNF3	1	450.10	184.73	722.32
TENSF70	1	464.53	202.89	714.89
TENSF65	1	462.73	200.58	694.81
TENSF55	1	457.61	197.92	718.15
TENSF75	1	457.61	212.89	718.85
TENSF50	1	453.02	181.89	722.32
TENSF60	1	462.13	199.01	710.54
SLIGHTLY RISK AVERSE (.0001 to .0004)				
TENSF75	1	457.61	212.89	718.85
TENSF70	2	464.53	202.68	714.89
TENSF65	3	462.73	200.58	694.81
TENSF60	4	462.13	199.01	710.54
TENSF55	5	457.61	197.92	718.15
STRONGLY RISK AVERSE (.0004 to .001)				
TENSF75	1	457.61	212.89	718.85
TENSF70	2	464.53	202.68	714.89
TENSF65	3	462.73	200.58	694.81
TENSF60	4	462.13	199.01	710.54
TENSF55	5	457.61	197.92	718.15

The risk-preferring group that chose DYNF2 to TENSF75 applied an average of 10.0 inches of water for an average yield of 794.8 pounds per acre. Those decision makers who preferred TENSF75 chose to apply an average of 7.8 inches of water to produce 798.3 pounds per acre. The net returns for these two strategies differed by $8.50 per acre. The risk-averse group of decision makers chose the higher threshold strategy, TENSF75, and applied less water. This was not expected since irrigation water is usually considered to be a risk-reducing input. The lower threshold strategy, TENSF55, should have resulted in a lower probability of low incomes, but due to the weather conditions in the low yield years, the low threshold strategy resulted in a higher probability of low incomes. Since risk-averse decision makers are more concerned with low yield years, they chose the higher threshold strategy to decrease the probability of low incomes.

Price Uncertainty

The introduction of price uncertainty into the decision problem can influence the strategies preferred by each group of decision makers. Boggess et al. (1983) demonstrated this by introducing soybean price variability to a risk-averse group of decision makers in a Florida study. They found that under price uncertainty, risk-averse farmers chose to irrigate less frequently and with larger amounts of water than that called for by the maximum net returns strategy (Boggess et al., 1983).

For this study, price uncertainty was introduced through the use of historical prices. Each of the 23 yields per strategy was multiplied by the real price of cotton for that year. These prices were untrended and were converted to constant dollars. The Index of Prices Received By Farmers in 1982 was used to deflate the price series. The average real price received by farmers in 1982 dollars was 58 cents per pound. This is substantially lower than the 65 cents per pound price used to calculate net returns for this study. The lower price changed the net return rankings for the strategies. This deflated price does not include deficiency payments.

Once again, the strategies were analyzed relative to the two irrigation systems. There were no comparisons made between the systems.

Center Pivot System

With the introduction of price uncertainty, the efficient set changed for each group of decision makers. TENSCP45, with average net returns of $481.93 per acre, was the efficient strategy for all four decision groups. TENSCP45 was the profit maximizing strategy, and as such, it was not expected to be the efficient strategy for the risk-averse decision makers. Under conditions of price uncertainty, most risk-averse decision makers move away from the profit maximizing strategy in an attempt to decrease the probability of low net returns (Table 11).

Furrow System

The results for the furrow system conformed more closely to expectations. The decision groups ranging from risk preferring to slightly risk averse found the profit maximizing strategy to be the only strategy in each of their respective efficient sets. TENSF60, with average net returns of $469.39, was the risk-efficient strategy

Table 11

COTCROP-A Model Results for Selected Cotton Irrigation Strategies Under Uncertainty[1]

CENTER PIVOT STRATEGIES	AVERAGE YIELD	AVERAGE NET RETURNS
TENSCP45	826.9	481.93 (1)
TENSCP50	827.8	478.21 (3)
TENSCP55	825.6	476.99 (5)
TENSCP60	823.40	476.26 (6)
DYNCP2	829.5	479.03 (2)
DYNCP3	827.3	477.25 (4)

FURROW SYSTEM STRATEGIES	AVERAGE YIELD	AVERAGE NET RETURNS
TENSF60	812.1	469.39 (1)
TENSF65	810.8	452.97 (3)
TENSF70	809.0	469.21 (2)

1 Price uncertainty was only introduced to the strategies whose net returns were within a three dollar range of each other.

for the risk-preferring, approaching risk-neutral and slightly risk-averse decision groups (Table 11).

The strongly risk-averse decision group found TENSF70 to be the risk-efficient strategy under price uncertainty. This irrigation schedule produced an average net yield of 809 pounds per acre, with average net returns of $469.21 per acre.

Model Errors and the Estimation of the Probability Distributions

Utility functions are estimated with one variable, income, and are assumed to be represented by an interval rather than a precise measurement. Each of the irrigation strategies produced a probability distribution of net returns. Unlike the utility functions used in the stochastic dominance analysis, it is assumed that the probability distributions are measured accurately.

With utility functions, the relative sizes of the preference intervals allow two types of errors to occur. A Type I error results when a preferred action choice is omitted from the efficient set. A Type II error results when a non-preferred action choice is included in the efficient set. The probability of incurring a Type I error can be reduced by increasing the probability of a Type II error, and vice versa, by adjusting the size of the preference interval.

Since the probability distributions are assumed to be accurate, i.e. they are not represented by intervals, the opportunity to adjust a particular type of error does not exist. With these distributions, Type I errors are the concern and they occur through measurement errors in the model.

In the process of adapting COTCROP to reflect Arkansas growing conditions, several problems were discovered. The soil component and the irrigation component of the model presented the greatest difficulties.

The water stress table in the soil component adjusts plant growth to reflect the soil moisture status (Table 12). The relationships presented in the original documentation stated that when the tensiometer reading was at 0.0 atm, 100 percent of plant growth was realized. This obviously is not correct. With a tensiometer reading of 0.0 atm, the soil is completely saturated, the plant receives no oxygen and growth is inhibited. Some crude calibrations were made in an attempt to correct the soil moisture/plant growth relationships represented in Table 12. These calibrations may be one source of measurement error.

This model also assumes a uniform soil profile which is not representative of many Arkansas soils. The nonuniform soil profiles charateristic of this study area were unable to be incorporated into the model, therefore, the plant growth measurements may be inaccurate. These measurement errors may have affected yield estimates.

Another problem observed in the soil water balance portion of the model had to do with the drainage of the soil. In some cases, rather than being drained from the soil profile, water was actually pulled up from the water table. Although this weeping soil is observed in some parts of Arkansas, the model was not designed to capture this activity. The program should have kept water constant at the end of each day, or allowed it to decrease. On the days when no rainfall occurred, water was drawn from the water table. This weeping soil

Table 12

Cotton Water Stress Tables

Original Documentation (COTCROP)

Tensiometer Reading	Percentage of Potential Growth
0.0 atm	100
-.33 atm	95
-.60 atm	40
-1.0 atm	10
-3.0 atm	5
-4.0 atm	5

Revised Table (COTCROP-A)

Tensiometer Reading	Percentage of Potential Growth
0.0 atm	0
-.33 atm	95
-.60 atm	85
-1.0 atm	10
-3.0 atm	1
-4.0 atm	0

activity may be reflected in the yield estimates.

Other observations stemming from the weeping soil problem were evident when sensitivity analysis was conducted in an attempt to validate the model. In a day-by-day comparison of one irrigation strategy to the no irrigation strategy, results showed that three days after the irrigation application, more water was present in the soil profile of the dryland production run than in the irrigated run, even after no rainfall was recorded.

This same problem may be reflected in another interesting phenomenon observed among the strategies. In certain years, the non-irrigated yields exceeded the irrigated yields. This occurs most regularly in 1961, 1969, 1976, 1979 and 1982 (see Tables 13 and 14). For some of the irrigation strategies, in the years 1961 and 1979, the non-irrigated yields tie the estimated yields of the irrigated strategies. According to the weather data, 1961 and 1979 were very wet years with good sunlight. Both 1969 and 1976 were fairly wet years with moderate sunlight and 1982 was an extremely dry year with moderate sunlight (Table 15). There does not appear to be a specific type of weather year that causes non-irrigated yields to exceed irrigated yields.

These problems require that the results be interpreted with caution. It is unclear how sensitive the rankings of the strategies by either criteria (profit maximization or risk efficiency) will be to the model errors. Additional work is now underway to correct COTCROP-A. Further discussion of the results and model may be found in Harp (1985).

Table 13

Years Non-Irrigated Cotton Yields
Exceeded Irrigated Strategy Yields:
Center Pivot System

TENSCP45	TENSCP50	TENSCP55	TENSCP60	TENSCP65	DYNCP2	DYNCP3	CALCP
1969	1961	1961*	1961*	1961*	1961	1961	1961
1976	1969	1962	1976	1969	1962	1962	1962
1979	1976	1969	1979	1976	1969	1969	1963
1982	1979	1976	1982	1979*	1976	1976	1964
	1982	1979		1982	1979	1979	1968
		1982			1982	1982	1971
							1976
							1981
							1982

*yields for non-irrigated simulations were equal to yields for the specified irrigation strategy

Table 14

Years Non-Irrigated Cotton Yields
Exceeded Irrigated Strategy Yields:
Furrow System

TENSF45	TENSF50	TENSF55	TENSF60	TENSF65	TENSF70	TENSF75	DYNF2	DYNF3	CALF
1961	1961	1961*	1961*	1961*	1961*	1961*	1961	1961	1961
1962	1962	1962	1962	1962	1962	1969	1962	1962	1962
1968	1969	1969	1969	1969	1963	1979	1968	1968	1964
1969	1976	1976	1976	1976	1969	1982	1969	1969	1968
1976	1982	1979	1982	1979*	1976		1976	1976	1977
		1982		1982	1979		1982	1979	1979
					1982			1982	1982

*yields for non-irrigated simulations were equal to yields for the specified irrigation strategy

Table 15

Seasonal Summaries of Solar Radiation and Precipitation from the Stoneville Weather File

Year	Solar Radiation[1]	Precipitation[2]
1960	79896.	19.45
1961	74031.	21.66
1962	95326.	17.94
1963	87911.	20.40
1964	86429.	11.67
1965	88491.	15.00
1966	73734.	9.63
1967	72808.	13.71
1968	77016.	23.23
1969	75666.	14.81
1970	75390.	11.94
1971	70142.	22.86
1972	76391.	14.76
1973	69214.	13.48
1974	69371.	22.39
1975	72560.	19.85
1976	72762.	17.77
1977	82299.	19.03
1978	82164.	25.27
1979	80906.	22.54
1980	82214.	14.78
1981	77744.	17.49
1982	75427.	12.78

1 Solar Radiation reported in Langleys for the length of the growing season.

2 Precipitation reported in totals inches for the growing season. Growing season extended from May 5 through October 2.

CONCLUSION

The results from the two bio-physical, crop growth models, ASICM and COTCROP-A, demonstrate the superiority of current scheduling strategies which employ soil moisture monitoring. In both crops, significant differences in expected yields and net return were observed between these strategies and the non-irrigated strategies. In no case were the calendar or non-irrigated strategies ever risk efficient. The soil monitoring strategies produced higher expected yields, achieved greater average net returns and were risk efficient.

However, differences between the soil moisture monitoring strategies were difficult to detect. Soil water retention characteristics of the Crowley Soil can probably explain this result. In the soybean analysis, only strategies with either very high or very low thresholds could be easily distinguished. Examples would include: (1) tensiometer thresholds of -.80 bars or -4.0 bars and (2) capacity thresholds of 50 percent of extractable water. In the cotton analysis, no tensiometer strategies had mean net returns that differed from any other.

The ranking of the strategies by risk efficiency varied by degree of risk aversion. As risk aversion increased soybean strategies moniitoring the only top 15 cm of the soil profile became preferred. Tensiometer thresholds in the range of -.40 and -.50 bars seem to be most commonly preferred values. On the cotton side, different results were observed for the two irrigation systems. For the center pivot system, the more risk-averse decision makers would have a preference for the tensiometer strategy using a threshold of -.65 bars. The risk-preferring group would select the threshold of -.50 bars. For the furrow system, due primarily to the larger applications, slightly different results were produced but the same general pattern prevailed. The more risk-averse groups preferred the tensiometer strategy employing a threshold of -.75 bars. For the risk-preferring group, the dynamic strategy, DYNF2 (-.45 bars from first square to six weeks past first bloom followed by -.55 bars during the eight weeks after first bloom) maximized expected utility.

In both models, enhancements to their simulative capabilities can be made and work is underway to achieve such improvements. Additional calibration to Arkansas growing conditions will be necessary before the models can successfully make the transition from research to management uses.

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