DECISION CRITERIA FOR IRRIGATION SCHEDULING UTILIZING CROP GROWTH SIMULATION, RISK ANALYSIS AND WEATHER FORECASTING

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PREFACE

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CHAPTER I

INTRODUCTION

Significance of Irrigation

Water is a key resource for agriculture. It is a major limitation to agricultural crop production in many parts of the United States and the world. Even in humid areas of the United States, severe yield reductions can occur due to poor distribution and timing of rainfall events.

Irrigated cropland accounted for about 14% of the nation's total harvested land area in 1982, but represented approximately one-fourth of the total crop production (U.S. Department of Commerce, 1984 and 1985). This illustrates the importance of irrigation on a national scale. Regional and local economies can be even more heavily impacted by irrigated agriculture. Seventy-five percent of the nation's irrigated land area lies in the 17 western states. Table I, a summary of the U.S. Agriculture Census since 1944, shows that nearly 20 million hectares (49 million acres) were irrigated in 1982. This estimate could be considered low since the National Resources Inventory, conducted by the Soil Conservation Service in 1977, reported 24 million hectares (60 million acres). That study included lands that had been irrigated at least twice in the previous four

TABLE I

IRRIGATED HECTARES OF THE TOP TWENTY STATES AND THE UNITED STATES

STATE	THOUSANDS OF HECTARES IN THE INDICATED YEAR 1944	1954	1964	1974	1978	1982	IRR. LAND IN 1982 AS % OF TOT. HARVESTED CROPLAND*
CA	2005	2853	3077	3137	3483	3426	97
NE	256	474	878	1606	2307	2495	35
TX	534	1906	2585	2670	2841	2257	27
ID	820	941	1134	1157	1420	1397	71
CO	1093	916	1089	1164	1400	1296	53
KS	39	134	406	814	1087	1082	13
MT	630	766	766	712	845	819	22
AR	117	347	394	384	682	819	27
OR	457	603	651	6321	777	732	55
WA	211	315	466	530	681	663	31
FL	90	173	490	631	806	640	60
WY	548	511	636	591	682	634	86
AZ	298	477	455	467	490	445	105
UT	455	434	442	393	480	438	97
NV	273	230	334	315	364	336	137
NM	217	263	329	351	366	327	62
LA	217	287	235	284	276	281	15
GA	--	10	26	45	187	233	12
OK	1	44	122	209	244	199	5
MI	--	53	48	66	126	174	8
ALL OTHER STATES	56	226	430	540	1037	1195	
TOTAL 50 STATES	8315	11964	15000	16710	20582	19839	

*Irrigated land includes pastures and other lands that are irrigated but not harvested cropland.

Source: U.S. Department of Commerce, 1985 and earlier years.

years. One-half of the top 20 states have over 50% of their total harvested cropland under irrigation and all but Florida are western states. The reported total irrigated area peaked in the 1978 census, although irrigation is still expanding in certain areas, particularly in the southeastern United States.

As shown in Table II, agriculture accounted for nearly half of the total U.S. water withdrawal and over 80% of the water consumption in 1975. Table III indicates that agricultural water usage is primarily attributed to irrigation. In 1975, irrigation usage represented 81% of all water consumed in the U.S. and it is predicted to remain as the biggest consumer of water in the year 2000, at 68% of the total. In 1979, 46% of this water was supplied by wells, with the remainder supplied by surface water from either off-farm (44%) or on-farm (9.5%) sources (U.S. Department of Commerce, Farm & Ranch Irrigation Survey, 1982). The Second National Water Assessment survey (U.S. Water Resources Council, 1978) indicated that total water use exceeds stream flows in regions that account for 66% of the irrigated land. Nationally, about 25% of all ground water is used in excess of the ground water recharge rate.

Oklahoma's irrigated land base, while representing only a small fraction of the nation's, has important implications to Oklahomans, particularly in western and Panhandle counties. According to the 1985 Oklahoma Irrigation Survey (Kizer, 1985), 398,000 hectares (983,000 acres) had

TABLE II

WATER WITHDRAWALS AND CONSUMPTION BY FUNCTION, U.S., 1975.

USE CATEGORY	Percentage of Use by Category	
	Withdrawals	Consumption
Domestic and Commercial	8.5	6.9
Agriculture	47.5	82.8
Steam Electric Generation	26.3	1.3
Manufacturing and Minerals	17.2	7.7
Public Lands and Other	0.5	1.3
Total Use of All Categories	467 billion cubic meters	147 billion cubic meters

Source: Soil, Water and Related Resources, 1980 Appraisal, Part 1, USDA)

TABLE III

ESTIMATED ANNUAL FRESH WATER WITHDRAWALS AND CONSUMPTION FOR 1975, 1985, and 2000

FUNCTIONAL USE	FRESH WATER WITHDRAWALS (billion cubic meters) TOTAL WITHDRAWALS 1975	1985	2000	TOTAL CONSUMPTIVE USE 1975	1985	2000
Domestic	32.13	36.33	41.89	8.67	9.77	11.15
Commercial	7.64	8.35	9.30	1.53	1.68	1.89
Manufacturing	70.76	32.72	27.15	8.26	12.30	20.30
Agriculture						
Irrigation	219.29	229.67	212.53	119.34	128.22	127.80
Livestock	2.64	3.08	3.53	2.64	3.08	3.53
Power Generation	122.84	131.04	109.78	1.96	5.61	3.53
Mineral Production	9.74	12.20	15.65	3.03	3.84	4.98
Public Lands and Other	2.58	2.98	3.40	1.70	2.02	2.39
Total	467.62	456.37	423.23	147.13	166.52	175.57

Source: U.S. Water Resources Council, 1978

TABLE IV

IRRIGATION STATISTICS FOR TEN OKLAHOMA COUNTIES OVERLYING THE OGALLALA AQUIFER AND ALL OF OKLAHOMA

	10 Ogallala Counties	Total for Oklahoma	% of State in the 10 Counties
Number of Farms with Irrigation	1582	5696	28
Potential Irrigated Hectares	227097	398021	57
Actual Irrigated Hectares	159268	287804	55
Land Using Groundwater Source	143555	239010	60
Number of Wells	2563	6389	40

Source: (Kizer, 1985)

irrigation facilities and 288,000 hectares (711,000 acres) were actually irrigated. Fifty-five percent of the irrigated land is concentrated in an area encompassing Beaver, Texas, Cimarron, Harper, Woods, Ellis, Woodward, Roger Mills, Beckham and Dewey counties (Table IV). Nearly all of the irrigated land base of this area depends upon the Ogallala Aquifer as the source for irrigation water. Eighty-three percent of the state's irrigated land receives water provided by groundwater sources. In the ten county area described above, 97% of the water for irrigation is from groundwater sources. Irrigation in this region particularly is dependent on the availability of economical energy supplies.

Table V, a compilation of energy sources for irrigation in Oklahoma, illustrates that natural gas is the predominant energy source, although it is almost exclusively used in the far western counties. Electricity is the next most common energy source, followed by liquefied propane gas, diesel and gasoline. Energy requirements estimated in 1977, as the baseline for the Oklahoma High Plains Study (Oklahoma Water Resources Board, 1982), were 1.1 billion kilowatt-hours (3750 billion BTU). Individual energy source requirements were listed as 5.75 million kilowatt-hours of electricity, 10.05 million cubic meters (3.55 million MCF) of natural gas and 0.68 million liters (0.18 million gallons) of diesel fuel.

The implication drawn from this information is that

TABLE V

1985 IRRIGATION ENERGY SOURCES FOR OKLAHOMA

	HECTARES OF LAND		
Energy Source	Groundwater Source	Surface Water Source	Total
Natural Gas	155,405	2,660	158,065
Diesel	125,804	6,972	19,552
LPG	19,568	12,912	32,480
Gasoline	1,819	1,764	3,583
Electricity	49,794	5,434	55,228

Source: Kizer, 1985

nationally (and locally) irrigation is a large consumer of water and this consumption of water also requires a substantial energy investment. While many improved irrigation management techniques have been developed and incorporated into practice, better management techniques may still be developed and utilized, with a resultant reduction in irrigation water and energy requirements.

Problem Statement

As water and energy supplies continue to become more scarce and, in the long-term, more expensive, impacts on irrigated crop production make improved water management vital to the continued economic success of irrigated agriculture. One aspect of improved water management centers on the use of irrigation scheduling. Irrigation scheduling, in simple terms, is the determination of when and how much water to apply to meet specific management objectives. These production goals can be varied, ranging from maximum yield per unit area to maximum yield per unit of irrigation water applied. In today's economic climate in agriculture, the application of irrigation scheduling generally includes the goal of best net return.

Various criteria are used by irrigators to determine the schedule of irrigations and the amount applied. Some simply irrigate whenever a predetermined number of days has elapsed; often the number of days is controlled by the capacity of the irrigation system in relation to the area irrigated and crop water requirements. Others base their decisions on crop appearance with regards to the type of crop and its current stage of growth. Many scheduling programs involve measurement of soil water, using such instruments as tensiometers, resistance blocks, and neutron moisture meters. Still the information provided by the most sophisticated of these scheduling techniques merely provides guidelines to the irrigation manager, who ultimately decides the course of action based on his own experiences and preferences.

Many irrigation programs are based on maintaining the soil water in the active root zone of the crop above a predetermined optimal or critical value. Crop water use estimates are normally based on climatological conditions and crop characteristics. This method of scheduling represents improved management. However, the use of only critical soil water values does not take into account impending events that could greatly affect the optimality of applying irrigation at the prescribed critical time. The decision as to whether to begin irrigation or not is at the discretion of the irrigation manager who must base his decision on his analysis of current information and at least a subjective consideration of future conditions.

In recent years, through continued research and the subsequent understanding of certain crop physiological processes and the expanded capability (and availability) of computer systems, crop growth models have been developed for many crops. While not all physiological processes are well enough understood to be effectively modeled, many models are capable of providing reliable information about the effects of various management decisions, such as irrigation water applications, on a day by day basis. Crop growth models can therefore be used to analyze the effects of a current management decision against various probable events or test several management options against a probable future to determine the best course of action.

Enhancement of the irrigator's knowledge concerning the effects of current decisions on future events, and therefore future decisions, would result in improvement in the managing capability of the irrigator in meeting his desired production goal. Prediction of future outcomes will always be uncertain but certainly not unusable. Through the use of crop growth models, weather forecasts or probabilities, and risk analysis, evaluations of production risks can be made and management decisions can be reached with greater confidence.

Objectives

The major objective of this research is to examine, on a real-time basis, through the use of crop growth simulation, optimal irrigation management criteria when faced with uncertain future weather events. The decision-making process will involve elements of a risk analysis with a probabilistic prediction of future weather events and comparison of this probability to costs and losses associated with irrigation events. The specific objectives are:

1) Develop an irrigation scheduling decision model, incorporating the concepts of calculated risk and a crop growth simulation model, to compare the economic risk associated with deficient soil water to the cost of applying an irrigation application.
2) Evaluate the usefulness of the various forecasting sequences in determining improved irrigation schedules.

CHAPTER II

REVIEW OF LITERATURE

Optimization in Irrigation Management

The irrigated agricultural industry represents a significant portion of agricultural production but at a substantial investment of resources. Consequently, optimization of irrigation management strategies and systems has been actively pursued at many levels, ranging from individual to international in scope.

Optimization of irrigation systems has been approached by a variety of scientific disciplines using many optimization methodologies. Stewart and Hagan (1973), while developing guidelines for predicting and planning irrigation for their local conditions, summarized the value that such water research investigations will have in identifying improved solutions for the following problems:

1. Allocations of water to agriculture versus other uses.
2. Economic analyses of irrigation project plans and operations, and impacts on income as opposed to investment costs.
3. Assignment of priorities among potential water projects.

4. Design of water conveyance, distribution, and irrigation systems.
5. Allocations of water among projects, and among soil types and land area within projects.
6. Determination of water release and irrigation programs, and their effects on water use efficiency.
7. Planning of strategies for use of a limited water supply.
8. Assessing the economic impacts of water shortages in irrigated agriculture.

Yield Optimization

Optimization of irrigation practice has been approached from a number of directions, one of which has been to maximize yield. The studies in the following discussion have been limited to those involving some aspect of modeling. Numerous field experiments have been conducted to determine improved irrigation management practices, but are not included in this review.

Ahmed et al. (1976) stated that the broad purpose of irrigation is to minimize yield reductions due to water deficits. They developed a dynamic simulation model which they used to find the optimum use of a given quantity of irrigation water by evaluating the effect of various irrigation strategies on yield.

Anderson and Maas (1971) reported the use of a computer model to aid in evaluating and comparing alternative methods of distributing water among farmers. Once the response of various crops to variations of water supplies and the operating procedure used to distribute water were known, economic evaluations of irrigation practices and crop patterns were made through computer simulation trials.

Dean (1980) developed stochastic and deterministic models from which water application time series for humid climates could be synthesized. The results presented were for the deterministic model which was used to evaluate different water management strategy effects.

A number of yield simulation models for a variety of crops were successfully used by Hill et al. (1983) to improve yields, primarily through improved timing of irrigation applications.

Hill and Keller (1983) adapted previously developed crop models to match data from typical irrigation scheduling programs in their region. The effects of different schedules were estimated with the model by assuming normal weather for the future in conjunction with actual current year data to the present date. Yield was predicted as a function of estimated transpiration during each selected growth period.

Morey and Gilley (1973) presented a simulation model which they used to evaluate irrigation management practices. Hiler et al. (1974) noted that the stress day index (SDI) concept has application in optimization models for allocating water and found SDI treatments to have favorable results in field experiments.

Stegman et al. (1976) conducted field studies to determine the potential for relating plant water stress development to variables indicative of the prevailing soil and atmosphere environments. Data from the field studies were used to develop a model using plant stress criteria for determining when to irrigate. Simulation trials were conducted to compare schedules using plant stress criteria to conventional irrigation criteria.

Profit Optimization

Many of the previous studies were indirectly concerned with economic returns. The following studies had profit maximization as the primary objective.

Boggess et al. (1981) used a crop simulation model to study irrigation management criteria. The sensitivity of the maximum net returns strategy to crop and fuel price changes was also analyzed.

Bras and Cordova (1981) were concerned with the optimal allocation of water with an objective of maximization of expected profits. The status of soil water was considered at each irrigation decision point.

Burt and Stauber (1971) proposed that crop stress indicators could be the basis of determining irrigation schedules that meet economic optimization goals. These indicators were used in combination with data filtering techniques (methods to deal with uncertainty).

Fogel et al. (1976) selected an irrigation strategy which considered the possibility of rainfall while maximizing net returns to the farmer. Fortson et al. (1987) used historical weather data in a crop growth model to evaluate irrigation strategies.

Hart et al. (1980) developed the concept of a system optimal depth of infiltrated irrigation water. The system optimal depth had been defined as the average depth which must be infiltrated during an irrigation to bring about the maximum net income for that particular irrigation.

Lembke and Jones (1972) used a simulation model to compare various irrigation scheduling practices by developing profit-maximization curves for each practice. The scheduling criteria were based on beginning irrigation at specific levels of soils water or after an extended period of no rainfall.

Martin et al. (1983) and Martin and Heermann (1984) maximized profit as well. They found that a considerable amount of water can be saved by moving from a yield maximization to a net return maximization objective, but the optimal irrigation schedules were found to be sensitive to the yield model used.

Morgan et al. (1980) used a model to simulate the effects of various irrigation schedules on net returns. The irrigation scheduling criteria included irrigation at specific soil water levels and stages of growth.

Rhenals and Bras (1981) formulated a model to maximize net benefits. The optimization model includes the natural uncertainty of potential evapotranspiration.

Swaney et al. (1983a) grouped irrigation management studies into two general categories: (1) those attempting to determine an irrigation strategy based on weather patterns over many years, and (2) those designed to help develop a strategy during a particular year. The purpose was to develop a method to aid producers in developing a real-time irrigation strategy by taking into account current weather, energy costs and product price. Long-term irrigation strategies and real-time irrigation strategies were compared.

Windsor and Chow (1971) used maximization of expected profit to determine the type of irrigation system or level of irrigation which was best suited to the given condition. They noted irrigation system design is a complex procedure and a more complete model to account for additional variables needs to be considered, since the maximization of expected profit may not always be the primary objective of farm management. Variability in production and demand, and the associated variability in risk, may have important influences on the decision-making process.

An interdisciplinary research project in New Mexico (WRRI REPORT No. 170, 1983) developed an irrigated agriculture decision-making model that included a probabilistic precipitation model, water production functions and an economic decision strategy model. In all statistical comparisons of the dynamic program model and a physically based model, which used three threshold soil water levels, the dynamic model increased the average net revenues. Additionally, water demand functions were examined revealing an inelastic water demand for corn but elastic water demand for wheat and grain sorghum.

Alternative Management Goal Optimization

The literature presented has already indicated the complexity of modeling the irrigation system. Each component of the soil-water-plant-atmosphere continuum has an individual complexity and associated uncertainty, to say nothing of the interrelationships within the continuum. This means a variety of objectives and production constraints may be addressed in a particular optimization analysis.

Anderson (1968) described a simulation program to establish an optimum crop pattern for irrigated farms based on predicted preseason estimates of water supply, with the objective of highest net income.

Dudley et al. (1971), Hall and Buras (1961), Hall and Butcher (1968), and Harris and Mapp (1980) maximized profit subject to a constraint on water supply. Dudley (1972) extended this approach to estimate the expected benefits from allocating water optimally between seasons.

Dylla et al. (1980) determined irrigation practices that would maximize crop yields while minimizing nitrate leaching losses and drought-stressed area.

Howell et al. (1975) optimized irrigation decisions so that yield was maximized subject to a given water supply. Previously Howell and Hiler (1975) had noted that maximizing yield may not be a desirable goal for irrigation managers in that other production resources may not be utilized efficiently.

A number of presentations were made on the subject of irrigation scheduling at the ASAE conference, "Irrigation Scheduling for Water and Energy Conservation in the 1980's". Hammond et al. (1981) maximized evapotranspiration while minimizing applications of water, fertilizers, and pesticides. Harrington and Heermann (1981) reviewed an irrigation scheduling program that had previously been reported by Heermann et al. (1976). Farm operators in this cooperative program had management objectives ranging from yield maximization to minimization of irrigation and fertilizer costs. Rhoades et al. (1981) chose to conserve water, while avoiding yield loss. Schoney et al. (1981) suggested minimizing water consumption and energy cost, subject to maximum yield.

Khanjani and Busch (1982) determined the optimal farm water use for a multi-crop farm using a probability analysis of accumulated potential and actual evapotranspiration and a cost-benefit analysis of the irrigation system.

Kundu et al. (1982) showed that simulation models can be used to evaluate effects of irrigation water allocation on crop yield by determining: (1) optimum soil water depletion replenishment levels, and (2) timing and amount of irrigation during different crop growth stages. Results were presented for irrigation schedules developed to obtain maximum water use efficiency.

Lynne and Carriker (1979) outlined a conceptual basis for allocating water between various users. Integration of crop-water response information into the water allocation decision-making process allows the economic role of institutions in resource allocation to be examined.

Mapp and Eidman (1976) developed a simulation model that provided stochastic irrigated and dryland yield information as a function of soil water and atmospheric stress during critical plant growth stages. This information was used to evaluate methods of regulating groundwater irrigation usage.

Martin and Van Brocklin (1985) studied multi-year water allocations through the use of crop growth simulation with consideration of various management objectives, producer risk acceptance, and interest rates. Multi-year allocations resulted in increased average net returns and decreased annual variation of returns as compared to single-season management of deficit irrigation water supplies.

Pleban et al. (1983) determined short term surface irrigation schedules that minimize labor costs while meeting crop water requirements (no damaging stress) under water supply limitations. This is an extension of the study by Trava et al. (1977) and is further reviewed by Pleban et al. (1984). Trava et al. (1977) optimized irrigation water allocations using minimized labor costs while distributing a limited water supply without crop stress.

Ramirez and Bras (1985) approached deficit irrigation scheduling by applying a decision model that determined when and how much to irrigate based on measured soil moisture, available irrigation water and the time since the last rainfall occurrence.

Seginer (1983) emphasized the effect that water distribution uniformity has on the optimal allocation of land and water to a single irrigated crop with maximization of profit as the objective function.

Yearly weather variability influences on the irrigation schedule were noted by Smith et al. (1985). Their irrigation schedules were aimed at obtaining optimum yield by minimizing crop plant water stress.

Wu and Liang (1972) selected minimization of irrigation cost as the criterion in determining an optimal irrigation practice. This analysis was made for regions where no appreciable rainfall occurs but could be used in areas where effective rainfall can be described.

Zavaleta et al. (1980) used a simulation model to consider stochastic weather and/or institutional factors. The model was then used to identify irrigation strategies that maximized net returns, the effects of irrigation fuel curtailments on the optimum water distribution, and the associated impact on yield and net return.

Risk and Uncertainty in Irrigation

The decision-making process of farmers was studied by Johnson (1954). He noted that only in a situation with some uncertainty has management a function. If the outcome is certain, only operating instructions are needed and no alternative need be evaluated.

Risk and uncertainty play a role in agricultural production. Irrigated agriculture has traditionally been considered as a method of bringing stability to crop production through reduced yield variability (and reduced income variability). Although the literature presented thus far was reviewed with focus on the optimization procedures used, the variability and sensitivity of the optimal solution to physical production factors and simulation methodology were frequently noted. The following articles represent work where risk analysis was a consideration.

Boggess and Amerling (1983) used a bioeconomic simulation model to analyze risks and returns of irrigation investments. Weather variations and patterns have important impacts on investment profits. An interesting result from application of the model was that irrigation investment can actually be quite risky, in spite of irrigation being normally a risk-reducing input. The net effect is that while a farmer may reduce production risk through irrigation, an increase in financial risk may occur.

A review of approximately fifty irrigation scheduling articles by Boggess et al. (1983) revealed mainly single dimensional decision criteria and only three of those reviewed considered risk implications of irrigation. They identified five risk (variability) sources, all of which were quantified in the analysis, except for institutional uncertainty. Their study used a process simulation model to analyze the impact of alternative irrigation strategies on risks and net returns above irrigation costs, and results were presented for objectives of maximum net return, maximum yield, and maximum return per unit of irrigation water.

Cull et al. (1981a) used simulation to show that high irrigation efficiency depended on effective use of rainfall but the uncertainty of rainfall caused irrigation timing and water requirements to vary widely.

Two different types of potential evapotranspiration equations were used in three crop models for irrigation scheduling by Dugas and Ainsworth (1985). The choice of equation had a significant effect upon the water related model outputs and yields at the few locations tested. Sensitivity of the optimal irrigation schedule to the type of yield model had also been noted by Martin and Heermann (1984).

English et al. (1985) showed that deficit irrigation can lead to increased farm profits, particularly when water is limited or expensive, but cautioned that results are complicated by substantial uncertainty in the relationship between applied water and yield. English (1981) had previously written that this uncertainty may have significant effects on the optimal yield strategy. He argued that water-yield models that do not account for uncertainty of water use-crop yield relationships are inadequate because: (1) the relationship between applied water and crop yield is characterized by substantial and largely unavoidable error, and (2) this uncertainty may be so great as to significantly influence a farmer's irrigation practice. With consideration of uncertainty, the mean and variance of predicted income were used to determine optimal water strategies for a multiple crop system. He presented a simplified example to illustrate this concept and concluded that a real need exists for crop models that not only predict the most profitable yield, but also quantify the uncertainty of the yield prediction.

English and Orlob (1978) developed a general analytical model for dealing with the complex uncertainties in the relationship between irrigation water use and net farm income. They determined that optimal irrigation strategies which disregard uncertainty and utility may be substantially different than strategies accounting for uncertainty and utility. Utility is the decision maker's attitude toward risk.

Loftis (1981) presented a simple instructional example on the use of dynamic programming to establish the optimal timing and amount of irrigation applications. He concluded that the dynamic programming procedure provides a potentially powerful tool for scheduling irrigation but he too cautioned of limitations due to uncertainties imposed by the crop growth models.

Udeh and Busch (1982) selected the optimum land area to be irrigated, using a management strategy involving consideration of stochastic hydrologic events, probabilistic irrigation efficiency values and risk response functions of irrigators. They emphasized the uncertainty associated with using a fixed irrigation efficiency value which can result in serious errors in selecting the optimal irrigation system component. These errors can be greater than those associated with estimates of the evapotranspiration demand.

Calculated Risk and Weather Forecasts

Calculated risk is a decision-making process which involves a comparison of an expected loss to the cost of preventing the occurrence of the expected loss. In terms of irrigation scheduling programs, the expected loss could be yield reductions due to insufficient soil water; the cost of prevention could be the cost of applying irrigation water and preventing the insufficient soil water condition. Gringorten (1950) and Thompson (1950) applied the principle of calculated risk to repetitive operations where weather was the uncertain factor.

Thompson and Brier (1955) outlined the development of the calculated risk concept for weather sensitive operations. The concept is as follows:

If:	Then:
$P > C/L$	Protect
$P = C/L$	Either course
$P < C/L$	Do not protect

where:

P = the probability of the loss occurring,

C = the cost of protective measures,

L = the loss incurred should no protective action be taken.

The optimum long-run economic gain would be realized if protective measures are instituted according to the above criteria. In the case of irrigation scheduling, C is the cost of irrigation and L is the loss in the value of crop yield due to insufficient soil water.

A study by Thompson (1962) investigated the potential economic gains which might be achieved through additional meteorological research. The study considered gains that could be achieved by either further basic scientific studies in meteorology or operationally oriented research. The results suggested that the average potential gains from either research approach are similar and may range from 5 to 10% of the protectable weather losses.

Thompson (1963) illustrated the application of the calculated risk concept with an example using temperature forecasts and freeze sensitive equipment. The example demonstrates an improved method of analyzing weather forecast predictions allowing relatively inaccurate forecasts to be used beneficially.

McQuigg (1965) briefly reviewed literature pertaining to the problem of making weather sensitive decisions in agriculture, which he divided into the two disciplines of decision theory and farm management. The nature of the works cited by McQuigg as typical of decision theory can be summarized as follows:

> The main thesis was that one needs to know the magnitude of the cost/loss ratio for the specific weather-sensitive decisions before choosing a course of action.

McQuigg (1965) also included several examples of decision matrices of various levels of complexity with inclusion of both weather and non-weather factors. He concluded in his discussion that the mathematical and economic tools exist which allow one to think of a system that incorporates meteorological, biological and economic processes in the decision-making process and it is important to exploit any meteorological information in order to increase management skill.

The cost-loss ratio model as originally presented was based partially on the assumption that taking the protective measures eliminates all of the loss associated with the occurrence of the adverse weather. Murphy (1976) generalized the cost-loss model using the assumption that taking protective action may either reduce or eliminate the loss. The importance of this generalization is that the decision-making criteria are applicable to a wider range of situations.

An important part of the cost-loss model is the probability of occurrence of the particular adverse weather condition of concern to the decision making process. The economics of extended-term forecasting were examined by Anderson (1973). The discussion described a way of reacting to extended-term weather information and a comparison of various general categories of forecasts. Included were two case studies where the value of extended-period forecasting was determined.

Murphy (1977) also investigated the value of weather forecasts including the following types: (1) climatological (i.e., forecasts based upon climatological probabilities); (2) categorical or deterministic (i.e., forecasts derived from comparing forecast probabilities with some critical probability value); and (3) probabilistic forecasts. The effect of perfect forecasts in the decision making process was also included. The most important implication of the study relates to the fact that the value of even moderately unreliable probabilistic forecasts exceeds the value of climatological and categorical forecasts. The benefits expected from probabilistic forecasts do not depend on scientific advances in weather forecasting. This last finding is of particular importance when considering that some meteorologists feel weather forecasts did not improve significantly during the period from 1957 to 1976 (Ramage, 1978) and during the period from 1966 to 1978 (Ramage, 1982). Glahn (1985) takes exception to the method of analysis used by Ramage and suggests that there is strong evidence that the reliability of rainfall forecasts has improved during the period from 1967 to 1982. McCullough (1983) indicates that current short-term climate predictions have limited usefulness but their value will increase as ongoing research improves their dependability.

Allen and Lambert (1971a) discussed the principle of calculated risk. The general decision-making model combined weather forecast data, crop production information, and irrigation costs into a probability framework. Allen and Lambert (1971b) discussed the application of the calculated risk principle for a specific situation, from which they concluded the resulting irrigation schedule was superior to a scheduling program based on a specific level of soil water availability.

Fouss (1985) combined daily weather forecasts into a single daily rainfall probability used as an input to a water management simulation model concerned with using a drainage system to regulate soil water levels. The rainfall probability factor was used as a categorical type input, that is, if the probability of rainfall exceeded a predetermined critical value, a particular course of action was taken.

A dynamic decision making model was used by Brown et al. (1986) to investigate the economic benefits of forecasts in the fallow/plant situation for wheat. Current seasonal precipitation forecasts, issued by the National Weather Service, had minimal economic value, although modest improvements in the forecasts would lead to large increases in their value. The value of forecasts was sensitive to crop price and precipitation climatology.

Hashemi and Decker (1969) used climatological data and precipitation probability forecasts to quantitatively schedule irrigations. In this instance, the effects on crop yield were not evaluated as the analysis assumed maintenance of soil water above a critical value for crop yield damage. Benefits were gained by incorporating weather information into the decision-making process because of the resulting reductions in both frequency and amount of irrigation water applied.

Mishoe et al. (1982), Swaney et al. (1983a) and Swaney et al. (1983b) used SOYGRO, a soybean growth model, to make real-time irrigation decisions and evaluate the sensitivity of the analysis to various methods of predicting future weather conditions. The sequential use of the real-time decision model was superior to long-term strategy. The evaluation of model sensitivity indicated that averaged weather conditions were inadequate for model use. Historically based precipitation probabilities were superior to the averaged weather conditions but no additional improvements in profits were noted when daily forecasts of precipitation probabilities were used. They concluded that the lack of improvement with forecast probabilities was due to the nature of the tropical thundershowers of the region.

Benefits of Crop Model Use

Although certain limitations have been expressed, the literature presented has indicated that crop growth simulation has been successfully combined with various decision-making criteria in determining improved irrigation schedules. Successful use of such models is dependent upon clear understanding of the input requirements and model limitations.

The use of the principle of calculated risk in a decision-making process, such as the cost-loss model for irrigation scheduling, is dependent on being able to predict the yield response of the crop within the growing season. The development of crop models for simulation of crop growth processes is an important link in relating the calculated risk principles to irrigation scheduling.

Crop models contributed a significant portion of the information needed in many of the optimization procedures previously reviewed. Crop models have been developed for many crops; for example, in the studies reviewed and presented for this investigation, 13 different crops for which at least one crop model had been developed were noted.

The use of crop growth models, in combination with other models and decision-making criteria, has potentially added another dimension to the crop manager's decision-making capability. Ahmed et al. (1976) concluded that agronomically realistic simulation of water use and crop response is feasible and can be a useful tool for water resource management. Cull (1981b) noted that these types of models could be the bases of commercial management tools.

Amir et al. (1976) suggested that their model could be used for the following: (1) preparation of a detailed irrigation time table for irrigated multi-activity agricultural systems operating under uncertainties, (2) economic analysis of the existing hydraulic network, and (3) economic analysis of the farmer's habits and irrigation policy. Amir et al. (1980) generalized their comments about crop simulation models by stating that an interactive computerized aid is a tool in the construction of irrigation time tables and the application of such a tool has the following benefits:

1) Entering of data improves farmer familiarity with his system
2) Evaluation of potential improvements and management changes of the hydraulic network
3) User's role allows input of unquantified personal preferences
4) Rapid responses allow alternatives to be considered and
5) Better solutions are likely if the farmer

discusses the computerized results with an agricultural specialist.

SORGF Crop Model

Arkin, Vanderlip and Ritchie (1976) developed a grain sorghum model that simulates plant dry matter accumulation. The model is sensitive to many production inputs including row spacing, plant population, the type of hybrid, ambient temperatures, daily solar radiation and available soil water. Arkin et al. (1978) used a combination of the crop model and stochastic weather data to provide a realistic method of yield forecasting. Maas and Arkin (1978) prepared the users guide to SORGF, a dynamic grain sorghum model with feedback capability. Maas and Arkin (1980) performed a sensitivity analysis on SORGF. Results of the analysis indicate that the model shows a response to changes consistent with current understanding of plant/environment relationships.

Arkin et al. (1980) used the grain sorghum model and simulated weather data to forecast crop status during the growing season. The use of simulated data allows yields to be computed for any number of seasons from which the following can be determined:

1) the probability that a certain yield value might occur,
2) the most likely occurring yield,
3) the greatest and smallest occurring yield,

4) the probabilities that the yield may be greater or smaller than a particular value,

5) the average yield value expected over many years, and

6) the expected year to year variability in yields over many years.

Arkin and Dugas (1981) demonstrated the value of crop model simulation by using SORGF to evaluate various production management options, one of which was ratoon cropping. Ratoon cropping is multiple harvesting from a single crop planting by allowing regrowth between harvests. Simulation provided information about the potential of the practice for an area where little experience and no field research data were available.

Harris (1981) modified the Arkin et al. (1976) grain sorghum model to fit growing conditions in the Oklahoma Panhandle. Study results were also reported in Harris and Mapp (1986). The overall objective of the study was to determine irrigation strategies that permit the reduction of water and energy use for irrigated grain sorghum production while maintaining the level of net return. Comparisons of the contemporary irrigation schedule and various proposed irrigation schedules were made. Proposed strategies included initiation of irrigation at various critical soil water levels, withholding of irrigation at various stages of crop growth, and combinations of these criteria. Comparisons of these various irrigation strategies were made using stochastic dominance theory, to derive efficient irrigation strategies for risk averse producers, and optimal control theory, which does not consider producer risk preferences. In each instance, irrigation strategies better than the contemporary irrigation practices were identified.

Hornbaker (1985) used the modified Arkin grain sorghum model to derive near-optimal irrigation schedules for grain sorghum for Oklahoma Panhandle conditions. The methodology developed in this study adjusts both the scheduling of application and the quantity of irrigation water applied with variances in the unit value of the crop and cost of the irrigation.

Zavaleta et al. (1980) used a modified version of the Arkin et al. (1976) grain sorghum model to consider stochastic weather and/or institutional factors and allowed irrigation timing and quantity decisions to be based on an expected profit-maximizing criterion.

CHAPTER III

PROCEDURES

An important consideration for the successful completion of the objectives is the selection of the region to be used as the study area for this project. An early consideration, somewhat obvious, is whether the area has irrigated crop production that contributes significantly to the local or regional economy. Other considerations include the availability of: (1) quantifiable representative irrigation costs, (2) long-term climatological data, (3) weather forecast histories, and (4) a suitable crop growth simulation model for an important irrigated crop of the region.

Study Site

As already noted in the background information, Oklahoma has only a small fraction of the nation's irrigated land area. However a majority of this base is concentrated in the western and Panhandle counties and can be considered a subsection of the important High Plains region where water is supplied by the Ogallala Aquifer system.

The 1985 Oklahoma Irrigation Survey (Kizer, 1985) indicates that the three Panhandle counties accounted for nearly half of the state's irrigated land in that year. In this area of Oklahoma, a majority of the irrigated base is in grain sorghum (Kizer, 1985). Harris (1981) used the Panhandle counties to investigate irrigation scheduling of grain sorghum, as did Hornbaker in 1985. This area was also a part of the six state High Plains Ogallala Aquifer Study (Oklahoma Water Resources Board, 1983).

Harris (1981) and Hornbaker (1985) both used the grain sorghum model developed by Arkin et al. (1976). This demonstrates that many of the considerations listed as conditions for study site selection have previously been addressed with the exception of the availability of weather forecast history. Development of a forecast history was accomplished and will be detailed later.

The Panhandle counties of Oklahoma (Beaver, Texas, and Cimarron) meet the general criteria outlined as conditions of selection for the study site. The middle county of the Panhandle, Texas, has the largest potential and actual irrigated areas (Kizer, 1985). Texas County is also the location of a branch of the Oklahoma Agricultural Experiment Station with a research farm located near Goodwell, Oklahoma.

The general description of this area is that it is semiarid. During the summer growing season climatic conditions are characterized by sparse precipitation, high temperatures, and often strong winds, which combine to place high evapotranspiration demands on growing crops. Average annual rainfall is about 44 cm, of which the majority falls during the spring and summer months.

Texas County soils are dominated by three soil associations, Richfield-Ulysses, Richfield-Dalhart, and Mansker-Potter-Berthoud, accounting for nearly 90% of the land area. Over 64% of the county is classified as having Class III soils in the agricultural capability grouping. Class III is the highest ranking any soil receives in the area due to restrictions requiring practices to conserve water and control wind erosion. The soils are generally deep loams and clay loams (USDA, SCS, 1961).

Weather Forecast History

Three classes of weather forecasts were described by Murphy (1977) as climatological, categorical, and probabilistic. Using these definitions, only climatological and probabilistic forecasts will be investigated in this study, with the exception of the perfect forecast which will be described later.

Climatological Forecasts

Climatological forecasts are those based upon historical climatological probabilities. At Goodwell, Oklahoma, daily rainfall amounts since 1948 were available to prepare the following historical climatological rainfall probabilities:

1) Daily climatological probability,

2) Conditional daily climatological probability,
3) Daily climatological probability above a critical rainfall value,
4) Conditional daily climatological probability above a critical rainfall value.

Daily Climatological Probability. Daily climatological rainfall probabilities for May through October were calculated using the 1948-1986 weather record by summing the number of rainfall events recorded on a particular date and then dividing by the number of days on record. Although 39 years of rainfall data were used to develop the daily probability, the average daily probability values varied considerably from one day to the next, as shown in Figure 1. This variability is due to the relatively low frequency of rainfall and the length of weather record. Since such dynamic daily variation would not be expected for long-term averages, it was decided to smooth the daily climatological rainfall probability. This was accomplished by fitting a second degree polynomial through the daily values. This line is also shown on Figure 1. Some concern was raised due to a possible two week downward trend beginning about June 23 (day 174 on Figure 1). When the original data and several different fitted lines were used as inputs to the crop model, the irrigation schedule selection process was relatively insensitive to the particular form used. The second degree polynomial ($r^2 = 0.36$, std. error = 0.062) was selected since the regression analysis showed all

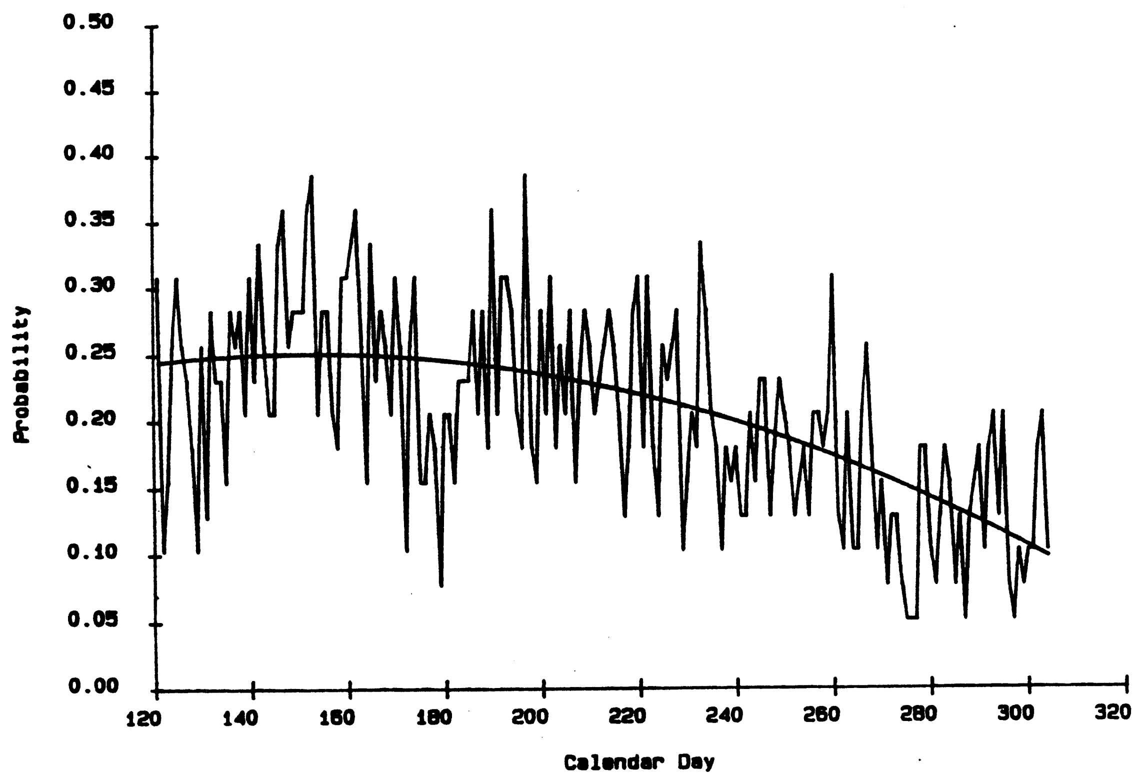

Figure 1. Daily Climatological Probability for Rainfall at Goodwell, OK.

coefficients were significant at the 5% level. The equation of the line is given by:

$$\text{Prob (rain)} = 0.098 + .002X - 6.56E\text{-}06X^2$$

where:

X = calendar day.

<u>Conditional Daily Climatological Probability.</u> The conditional daily climatological probability was calculated by noting whether the previous day was wet or dry and then noting whether the current day was wet or dry, as illustrated by Table VI. A wet day is defined as any day with recorded rainfall greater than zero.

In Table VI, the symbol WW represents the number of wet days given the previous day was wet while WD represents the number of wet days given the previous day was dry. Therefore two conditional daily probabilities can be developed based on events of the previous day. The daily conditional rainfall probability given the previous day had rain is WW / (WW + DW).

The smoothed daily conditional rainfall probability curves are shown in Figure 2. The conditional daily rainfall probabilities are not independent events and therefore best fit lines were not developed independently. In this instance smoothing of data was accomplished by first noting the number of observations of each of the following matrix elements: (DW + DD), (WD + DD), and DD. Best fit polynomials were then developed for each of these occurrences. The total number of observations was fixed at

TABLE VI

GENERALIZED CONDITIONAL PROBABILITY MATRIX TABLE

		Current Day: WET	Current Day: DRY	
Previous Day	WET	WW	DW	WW+DW
	DRY	WD	DD	WD+DD
		WW+WD	DW+DD	Total

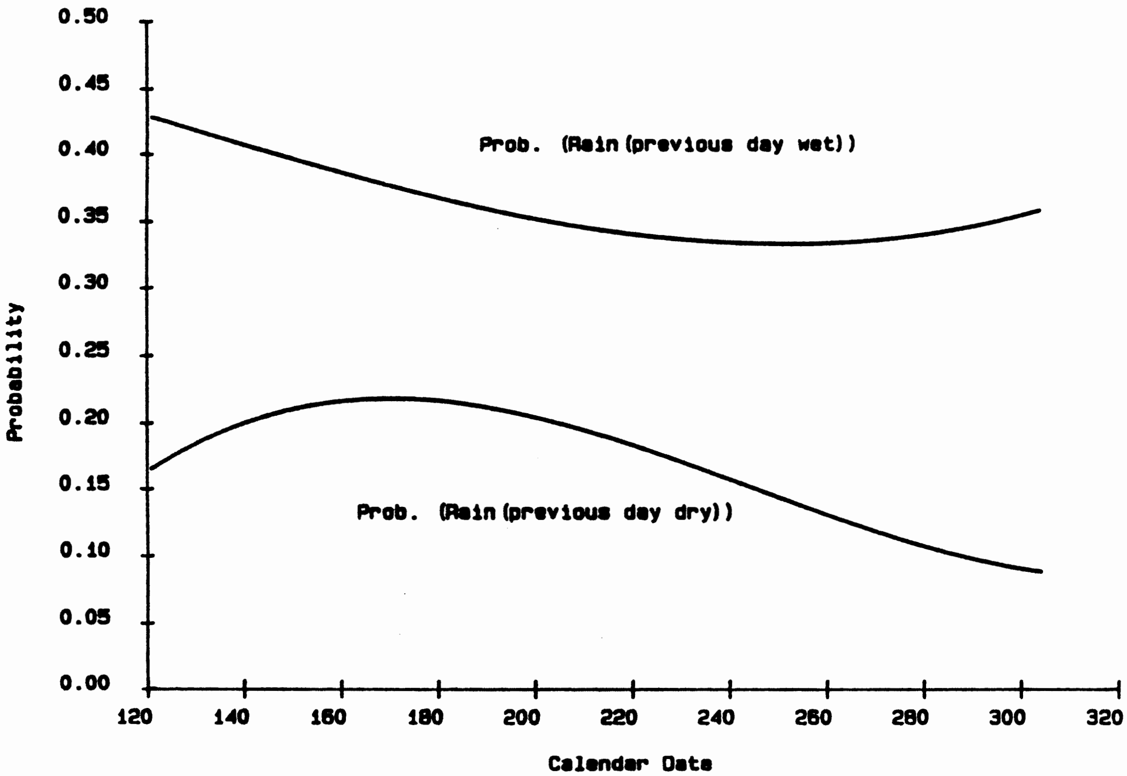

Figure 2. Conditional Daily Climatological Probability for Rainfall at Goodwell, OK.

39, the number of years of record. With these four numbers fixed, the remaining categories in Table VI can be calculated. This procedure allowed smoothing of the data, while preserving the relationships within the conditional categories and maintaining the correlation between days.

The best fit lines representing the daily conditional rainfall probabilities are the following third degree polynomials, which have statistically significant coefficients at the 5% confidence level:

$$\text{Prob (Rain(previous day wet))} = 0.545 - 5.58E{-}04X - 5.77E{-}06X^2 + 1.82E{-}08X^3$$

$$\text{Prob (Rain(previous day dry))} = -0.710 + 1.33E{-}02X - 5.99E{-}05X^2 + 8.19E{-}08X^3$$

where:

X = calendar day.

<u>Daily Climatological Probability Above a Critical Rainfall.</u> Daily climatological probability for rainfall amounts above 0.635 cm (0.25 inch) was also developed. Rainfall amounts as low as 0.025 cm are officially recorded. Such low amounts do not contribute significantly to the water needs of the growing plant. While evapotranspiration needs of a growing crop vary throughout the year, rainfall events greater than 0.635 cm will certainly contribute a significant portion, if not all, of a crop's daily water needs. Therefore the daily climatological probability for rainfall events above 0.635 cm was developed and is shown in Figure 3. The best fit line for this data, represented by a

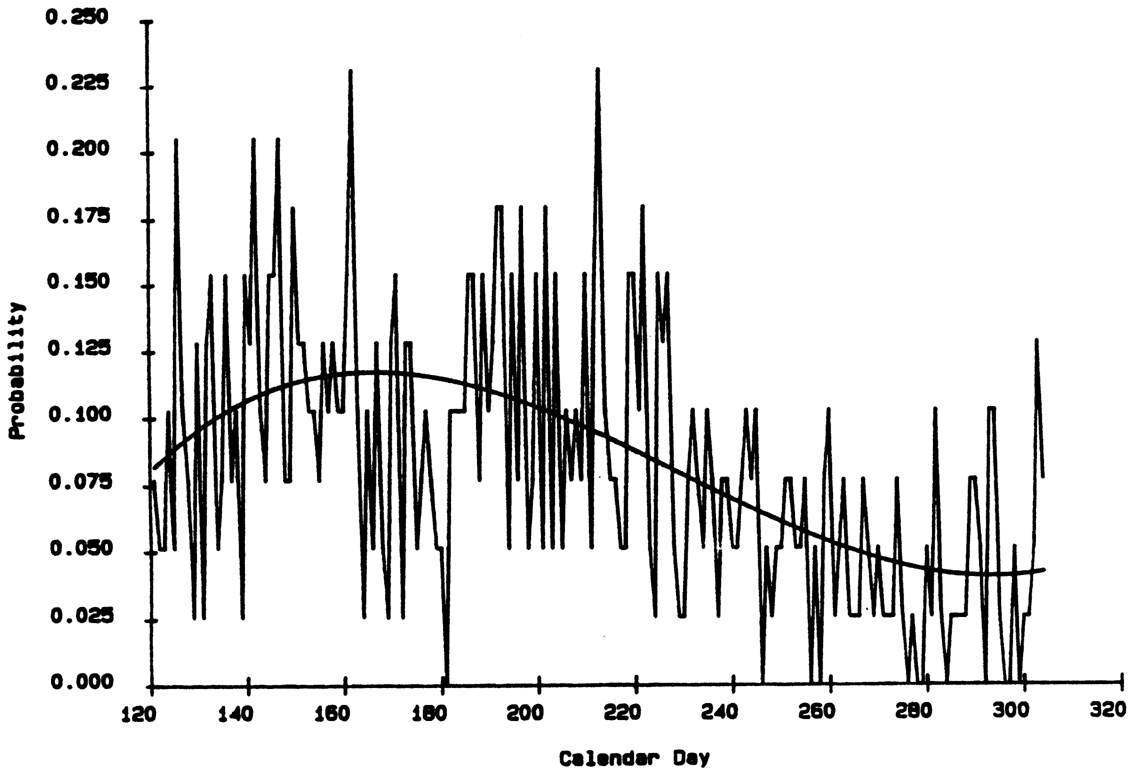

Figure 3. Daily Climatological Probability for Rainfall ≥ 0.635 cm at Goodwell, OK.

third degree polynomial (r^2 = 0.29, std. error = 0.044) with coefficients significant at the 5% level, is also shown and given by the relationship:

$$\text{Prob (Rainfall} \geq 0.635 \text{ cm)} = -.616 + 1.09E\text{-}02X - 5.14E\text{-}05X^2 + 7.46E\text{-}08X^3$$

where:

X = calendar day.

<u>Daily Conditional Climatological Probability Above a Critical Rainfall.</u> Daily conditional rainfall probability based on whether the previous day was wet or dry, and on whether the current day experienced rainfall above a critical amount, was developed. The critical rainfall amount was selected to be 0.635 cm. These conditional probability values, shown in Figure 4, were smoothed using the previously described procedure. The best fit lines (statistically significant coefficients at the 5% confidence level) for these daily conditional probabilities are as follows:

$$\text{Prob (Rain} \geq 0.635 \text{ cm (previous day wet))} = 0.069 + 3.08E\text{-}03X - 2.23E\text{-}05X^2 + 4.34E\text{-}08X^3$$

and

$$\text{Prob (Rain} \geq 0.635 \text{ cm (previous day dry))} = -0.780 + 1.27E\text{-}02X - 5.83E\text{-}05X^2 + 8.33E\text{-}08X^3$$

where:

X = calendar day.

Extended climatologically based rainfall probabilities were investigated. Probabilities for weekly rainfall, weekly rainfall greater than critical values, and

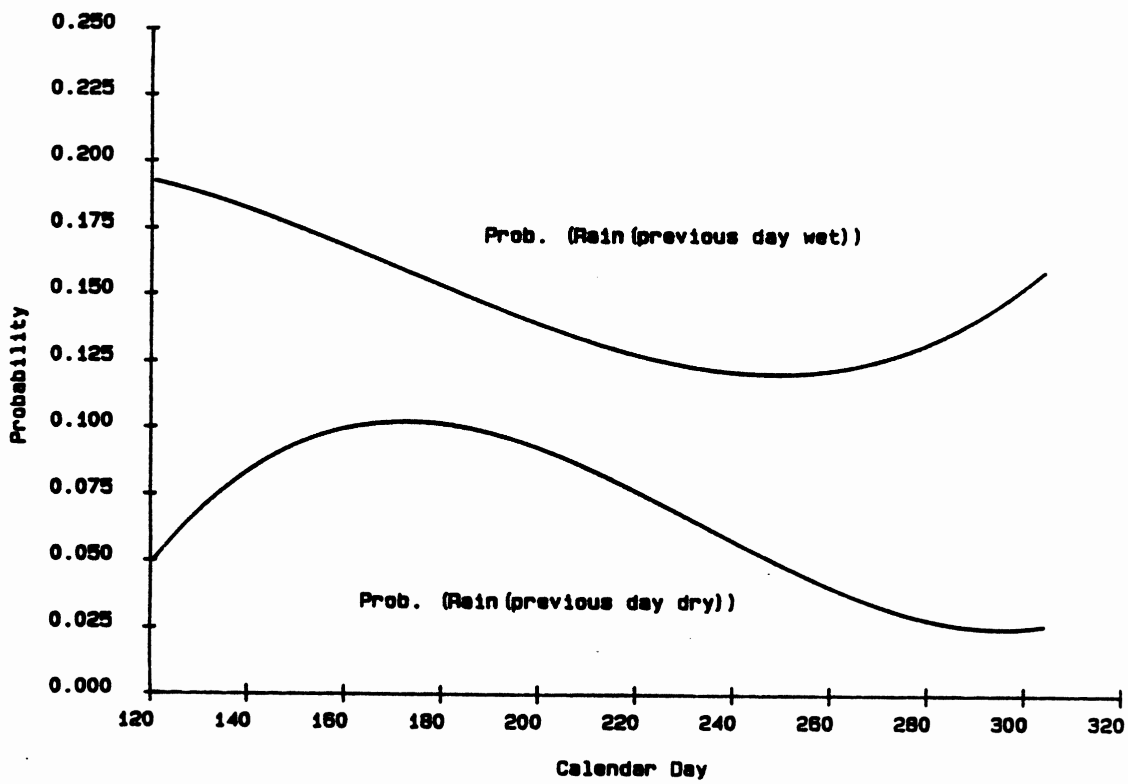

Figure 4. Conditional Daily Climatological Probability for Rainfall ≥ 0.635 cm at Goodwell, OK.

conditional weekly rainfall were developed for each week throughout the growing season, starting with the week beginning May 1. Weekly rainfall probabilities were not incorporated into the study due to problems of interpreting the meaning of a weekly forecast into a daily crop simulation model and, more importantly, decreased utility of extended climatological forecasts.

Professional Forecasts

The other general type of weather forecast to be investigated is the forecast prepared by professional meteorologists. The professional forecast or probabilistic forecast will be utilized as part of this investigation, along with several modified versions of the professional forecast. These modifications are investigated as possible methods to increase forecast utility and reliability. The following daily forecast rainfall probabilities were prepared:

1) Probabilistic forecast,
2) Comparative probabilistic forecast,
3) Conditional comparative probabilistic forecast,
4) Comparative probabilistic forecast above a critical rainfall,
5) Conditional comparative probabilistic forecast above a critical rainfall.

Probabilistic Forecast. The National Weather Service (NWS) issues weather forecasts four times daily for most areas of the country, although occasionally special updates and corrections are issued. Oklahoma is currently divided into 26 zones for which specific forecasts are made. These forecasts include the probability of rain during three consecutive 12 hour time periods, which for the early morning forecasts represent "today", "tonight", and "tomorrow". Rainfall probabilities are reported in increments of 10% from 20% to 90%. Forecasts are also made for less than 20% and near 100%. These predictions are made according to standardized criteria of the NWS (Mooney, 1987). The rainfall probability developed for each zone suggests that a specific location selected from within that zone will be at the probability level indicated. This is not tied to any particular rainfall amount.

The NWS archives zone forecasts at the National Climatic Data Center. Retrieval of this information was found to be prohibitively expensive. Zone forecast information is used by other reporting services, one of which is daily newspapers.

The Daily Oklahoman (1984,1985,1986), an Oklahoma City newspaper, presented sufficient detail of NWS zone forecasts to allow reconstruction of the forecasts for 1984, 1985, and 1986. Prior to 1984 the format of the weather section of the paper was generalized to a point that the original zone forecast information could not be reconstructed. Newspapers located near the study area also did not carry the specific zone forecast information. The 1987 zone forecasts were obtained from NWS wire service printouts obtained from KOSU, the Oklahoma State University radio station.

Only one value for daily rainfall probability could be recorded for each day in the first three years of record, since a consistent forecast for the three 12 hour periods could not be reconstructed. Days with no mention of rainfall probabilities were recorded as zero, days with "less than 20%" or "isolated showers" (NWS standardized criteria) were recorded as 10%, and near 100% was recorded as 100%. Since the NWS zone forecast was available for 1987, a daily probability value could have been developed combining the period forecasts into a combined daily forecast, in a manner similar to that of Fouss (1985) or Allen and Lambert (1971a). However, to make the 1987 forecast consistent with those reconstructed, the daily probability, coded as described previously, was simply recorded as the larger of the today or tonight value. In most instances, these values were identical.

The daily rainfall probabilistic forecasts for the study site are shown in Figures 5 through 8 for the years 1984 through 1987 (May through September), respectively.

Comparative Probabilistic Forecast. The comparative probabilistic forecast was prepared by comparing the probabilistic forecast to the actual rainfall record for corresponding days. For each level of daily forecast (0%, 10%, 20%, etc.), the weather record was checked for that day to see if rain had occurred. The number of rainfall events

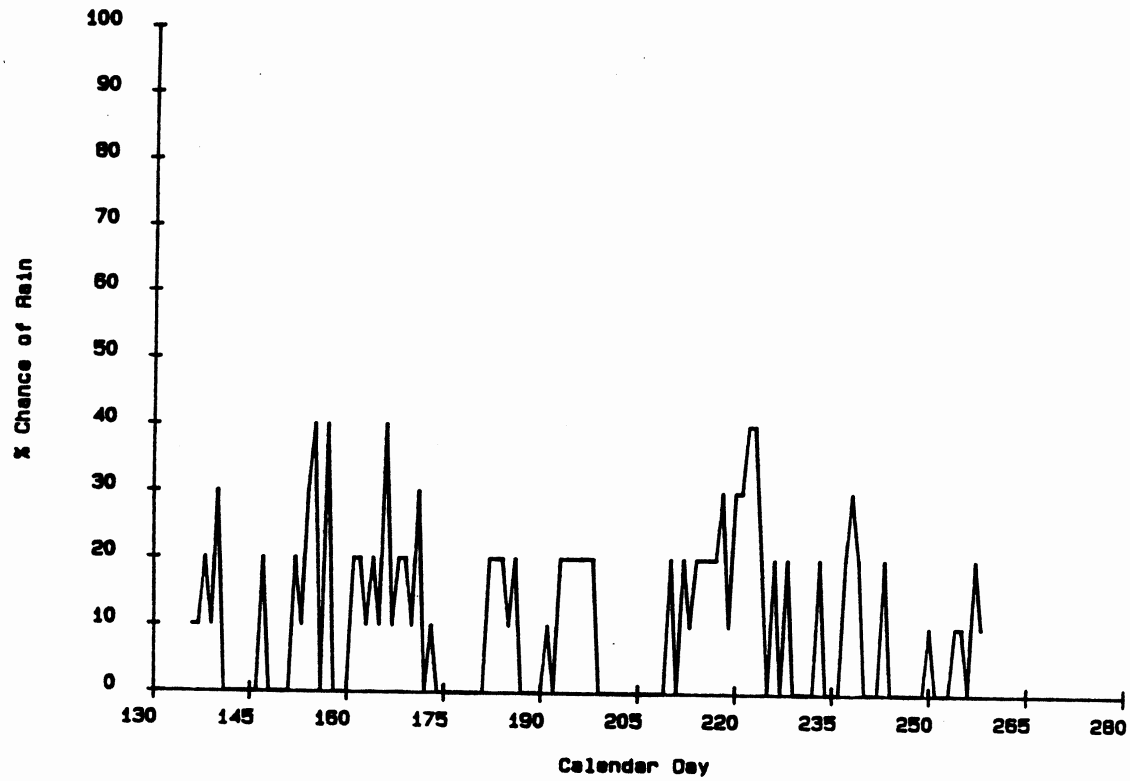

Figure 5. The 1984 Daily Probabilistic Forecast for Rainfall at Goodwell, OK.

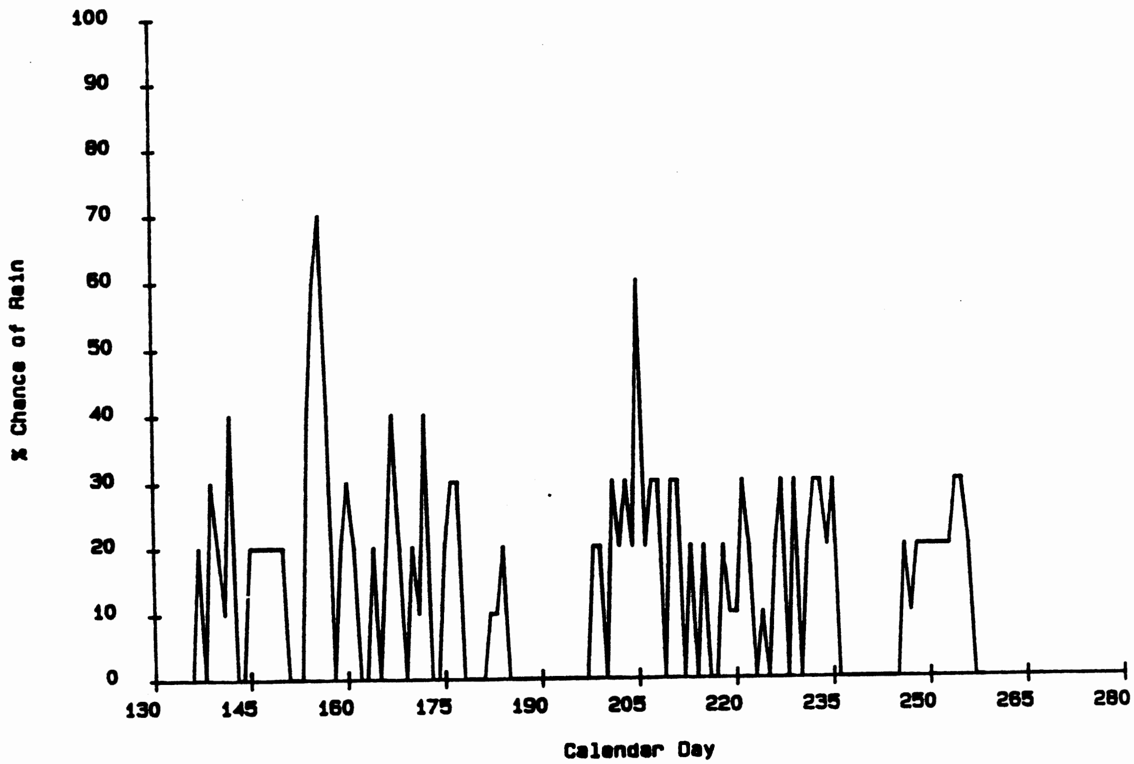

Figure 6. The 1985 Daily Probabilistic Forecast for Rainfall at Goodwell, OK.

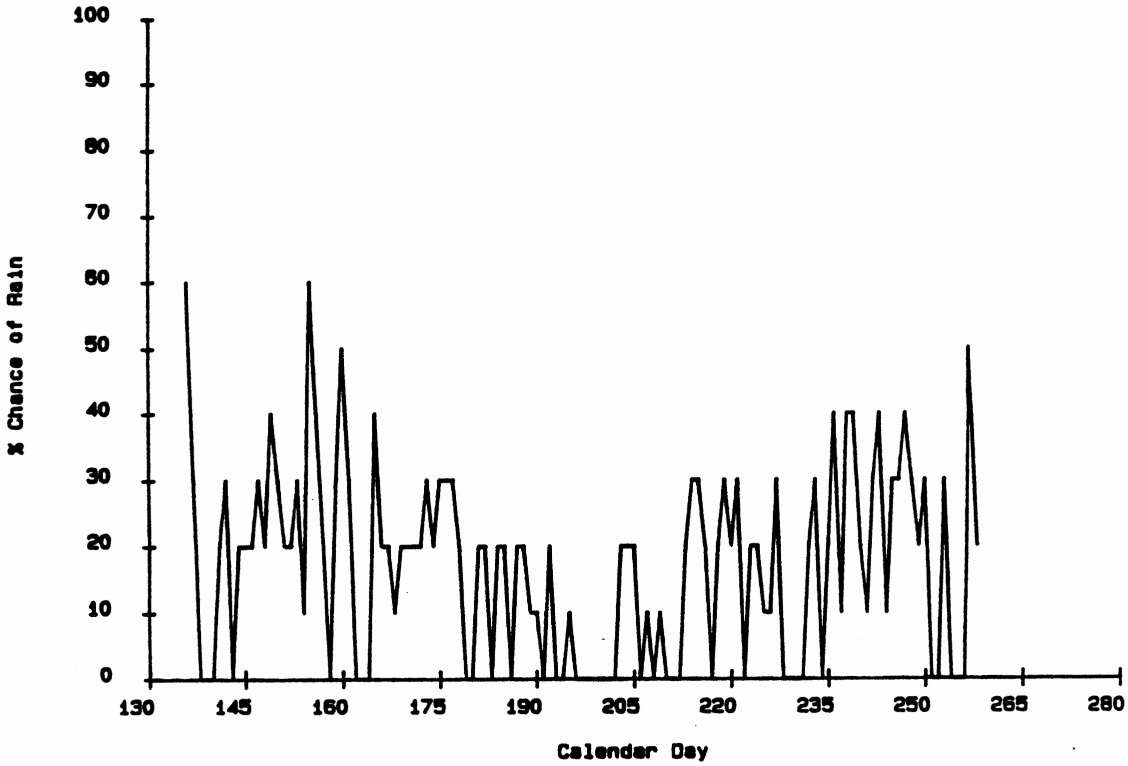

Figure 7. The 1986 Daily Probabilistic Forecast for Rainfall at Goodwell, OK.

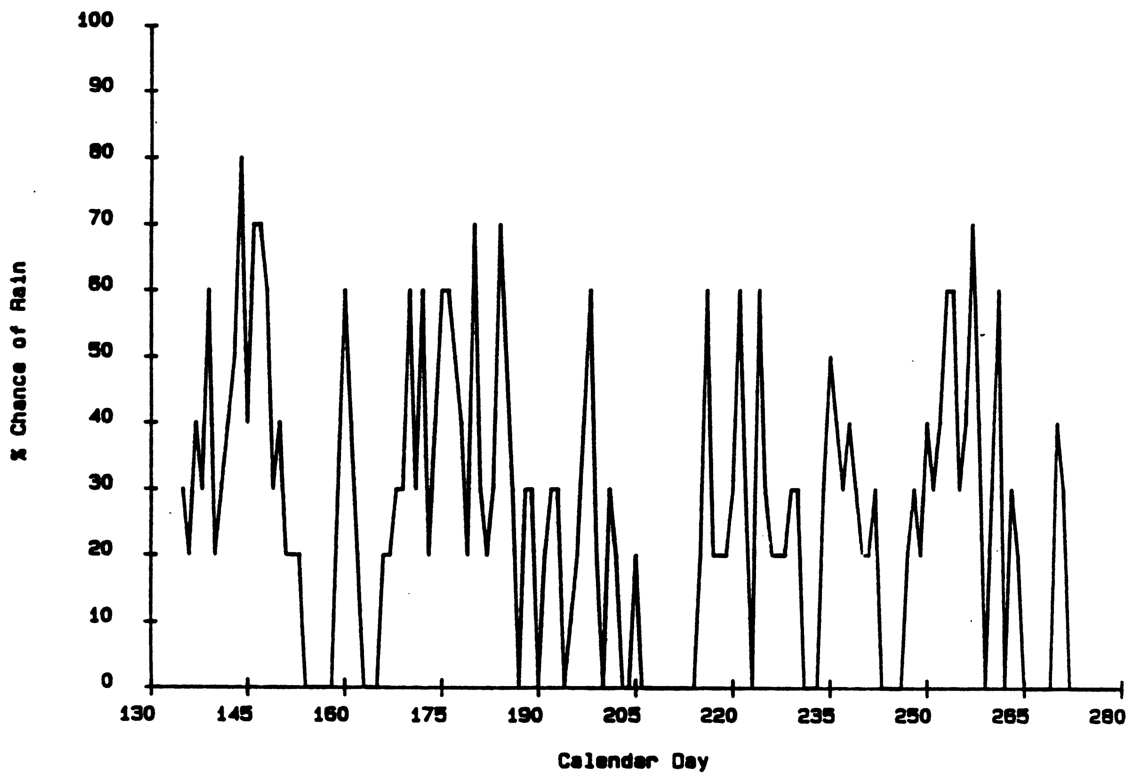

Figure 8. The 1987 Daily Probabilistic Forecast for Rainfall at Goodwell, OK.

for each forecast level was divided by the total number of occurrences of each forecast level to determine the comparative probabilistic forecast. The rainfall records for the four years for which forecasts were available were adjusted using the original observation sheets prepared by the on-site weather observers as to the time of occurrence of the rainfall event. This was necessary since all weather observations at the Goodwell Station are recorded at 8:00 AM, meaning the 24 hour rainfall amount recorded may have actually occurred on the previous day and therefore would not correspond with the correct daily forecast. The daily probabilities of the comparative forecast are shown in Table VII.

The number of occurrences of a particular forecast level is also shown in Table VII. These are shown to emphasize the limited number of occurrences of some levels of forecasts, as only four years of record were used in the comparisons.

Conditional Comparative Probabilistic Forecast. The conditional comparative probabilistic forecast was prepared by: (1) assuming the conditional portion of the analysis was represented by whether the probabilitistic forecast was above or below a critical value, and (2) then noting the number of rainfall occurrences in the total number of opportunities. This conditional probability could be represented by Table VI, if the conditions as to whether the previous day was wet or dry were changed to whether the

TABLE VII

COMPARISON OF RAINFALL FORECAST TO OBSERVED FREQUENCY OF RAINFALL FOR 1984 THROUGH 1987 (MAY THROUGH SEPTEMBER) AT GOODWELL, OK.

Forecast Value %	Number of Forecast Occurrences	Observed Rainfall Frequency
0	188	0.138
10	38	0.239
20	132	0.182
30	79	0.304
40	32	0.438
50	5	0.800
60	19	0.579
70	6	0.333
80	1	1.000

forecast was above or below a critical forecast level selected by the user. A series of conditional comparative probabilistic forecasts were generated by assuming critical forecast levels from 0% through 70% (Table VIII).

If, for example, the critical value of forecast level was selected to be 20%, then all forecasts at 0%, 10%, and 20% would be one conditional category (possibly thought of as a forecast for dry weather). Any forecasts for greater than 20% would be the second conditional category (the forecast for wet weather). The rainfall record is then examined to determine the number of times these two categories occurred and the number of times rainfall occurred in each. The probability is calculated by dividing the number of occurrences of rainfall by the number of categorical occurrences for each respective case. In this instance, the probability of rainfall given the forecast is 20% or less is 0.165, while the probability for rainfall is 0.394 if the forecast was given as 30% or greater.

Selecting high critical forecast values has the disadvantage of having a reduced number of occurrences, while selecting lower critical values has the disadvantage of decreased utility of information (less difference between the two conditional probabilities). The critical forecast value selected for use was 30%. A forecast of 30% or greater occurs 28.4% of the time in the record and provides a difference between probabilities of 0.318. Reducing the forecast value to 20% increases occurrence to 54.8% but

TABLE VIII

SERIES OF CONDITIONAL COMPARATIVE PROBABILISTIC FORECASTS FOR RAINFALL FOR 1984 THROUGH 1987 (MAY THROUGH SEPTEMBER) AT GOODWELL, OK.

Forecast Critical Value %	Observed Rainfall Frequency	
	Forecast > F.C.V.	Forecast ≤ F.C.V.
0	0.285	0.138
10	0.292	0.155
20	0.394	0.165
30	0.508	0.190
40	0.581	0.207
50	0.539	0.213
60	0.429	0.227
70	1.000	0.229

decreases the probability difference to 0.229. A forecast for 40% or greater occurs only 12.8% of the time and has a probability difference of 0.374.

Comparative Probabilistic Forecast with a Critical Rainfall. The comparative probabilistic forecast with a critical rainfall value was prepared in the same manner as the comparative probabilitistic forecast except that rainfall was defined as being at least 0.635 cm in magnitude. These probabilities are shown in Table IX.

Conditional Comparative Probabilistic Forecast with a Critical Rainfall. The conditional comparative probabilistic forecast with a critical rainfall value was prepared using the procedure described for the conditional comparative probabilistic forecast except that rainfall was defined to be at least 0.635 cm in magnitude. Table X presents the series of conditional probabilities that were developed. The critical forecast value was selected to be 30% for use in the model.

Perfect Forecast

A perfect forecast was prepared by examination of the rainfall record for 1984 through 1987. For any day that a rainfall event occurred, a probability of one was recorded. If no rainfall occurred a zero probability was entered into the record.

TABLE IX

COMPARATIVE FORECAST PROBABILITIES FOR RAINFALL ≥ 0.635 CM FOR 1984 THROUGH 1987 (MAY THROUGH SEPTEMBER) AT GOODWELL, OK.

Forecast Value %	Number of Occurrences	Observed Rainfall Frequency
0	188	0.032
10	38	0.105
20	132	0.008
30	79	0.101
40	32	0.188
50	5	0.200
60	19	0.316
70	6	0.167
80	1	1.000

TABLE X

SERIES OF CONDITIONAL COMPARATIVE PROBABILISTIC FORECASTS FOR RAINFALL $\geq$ 0.635 CM FOR 1984 THROUGH 1987 (MAY THROUGH SEPTEMBER) AT GOODWELL, OK.

Forecast Critical Value %	Observed Rainfall Frequency	
	Forecast > F.C.V.	Forecast $\leq$ F.C.V.
0	0.119	0.032
10	0.120	0.044
20	0.162	0.056
30	0.238	0.064
40	0.290	0.073
50	0.308	0.074
60	0.286	0.083
70	1.000	0.084

Model Description

As previously noted, grain sorghum is an important irrigated crop for Oklahoma. Arkin et al. (1976) recognized the value of crop growth simulation models as potential research and management tools and introduced a grain sorghum model. This model, later called SORGF, simulates the daily growth and development of an average grain sorghum plant in a field stand. While Arkin et al. (1976) described the major components of the model, the release by Maas and Arkin (1978) was a complete user's guide to SORGF, which included model input parameters and test data to allow the user the capability of testing modifications.

The SORGF model is comprised of a series of submodels that represent particular physical characteristics and physiological growth processes of a grain sorghum plant. Most of these submodels represent processes described by empirically derived equations. Arkin et al. (1976) noted that grain sorghum growth characteristics differ little over large areas of the U.S. due to photoperiod insensitivity and narrow genetic variability within maturity classes of varieties grown. A generalized flow diagram of SORGF is shown in Figure 9.

The input data required for SORGF are shown in Table XI. Specific input data for each or the four years are shown in Table XXXIX, Appendix A. The 1984 through 1987 weather record, and the historical average weather record

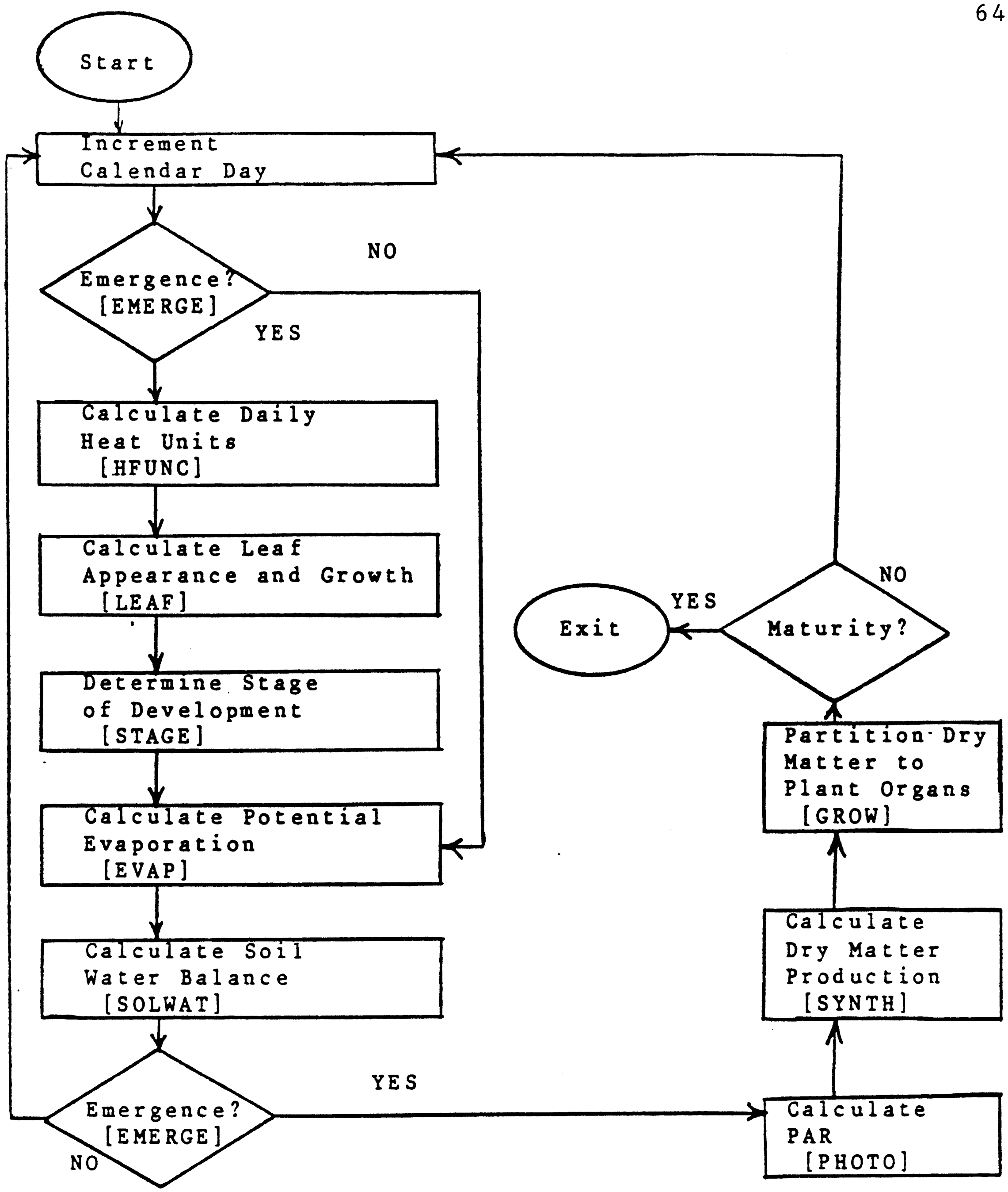

Figure 9. Simplified Flow Diagram of SORGF (after Maas and Arkin, 1978; Harris, 1981)

TABLE XI

INPUT DATA REQUIRED FOR SORGHUM SIMULATION MODEL

Plant data	
	Leaf number - total number of leaves produced
	Leaf area - maximum area of each individual leaf, cm^2
Planting data	
	Planting date - month, day, year
	Plant population, plants/ha
	Row width, cm
	Planting depth, cm
Climatic data (daily from planting to maturity)	
	Maximum temperature, ^oC
	Minimum temperature, ^oC
	Solar radiation, ly/day
	Rainfall, cm/day
Soil data	
	Available water holding capacity, cm
	Intial available water content, cm
Location data	
	Latitude, deg

Source: Arkin et al., 1976

are shown in Tables XL through XLIV in Appendix B, respectively. The historical average weather record is based on 39 years of record. The solar radiation information is based on 23 years of records from Dogde City, Kansas. Long-term solar radiation information was not available at the Goodwell study site. An important feature of the model for many applications in management and research is the ability to update certain plant parameters throughout the growing season as those data become available. These feedback parameters are shown in Table XII. Other parameters, such as available soil water, could be potential feedback parameters.

Detailed descriptions of each of the submodels of SORGF are available through Maas and Arkin (1978) and Arkin et al. (1976). The general function of each submodel shown in Figure 9 is presented below.

EMERGE is called after the planting date to determine the date on which the modeled sorghum plant emerges above the soil surface. The emergence procedure requires the date of seed germination to be calculated. Germination and emergence are functions of accumulated heat units. Germination is also affected by available soil water. Additionally, emergence is a function of planting depth.

HFUNC is the submodel that makes the daily calculation of heat units. Heat units are the difference between average air temperatures and a base temperature, although there is an upper limit to temperature as well.

TABLE XII

POSSIBLE SORGF DAILY FEEDBACK PARAMETERS

Date of emergence
Date of leaf emergence for each leaf
Leaf area for each leaf on day of feedback
Date each leaf achieves maximum area
Weight of plant organ on day of feedback
Stage of development on day of feedback

LEAF determines the calendar date on which each leaf appears and calculates the leaf area of each leaf on a daily basis. Leaf emergence is based upon accumulation of heat units. When the leaf area of a particular leaf exceeds the maximum value entered, leaf growth is complete. For each leaf added beyond the eleventh leaf, an earlier leaf, beginning with the first leaf, is lost. The total leaf area of the plant is adjusted for both emerging and senescing leaves.

STAGE determines the developmental stage of growth of the modeled grain sorghum plant. The five phenological growth stages are assigned according to the following morphological events:

Stage 1: Emergence to differentiation.

Stage 2: Differentiation to end of leaf growth.

Stage 3: End of leaf growth to anthesis.

Stage 4: Anthesis to physiological maturity.

Stage 5: Physiological maturity and beyond.

EVAP calculates the potential evaporation above and below the canopy as a function of climatic data. The potential evaporation above the plant canopy is calculated as a function of daily climatic data and then an estimate of the potential evaporation below the plant canopy is based on the magnitude of the leaf area.

SOLWAT calculates the daily soil water balance by adding to the previous day's soil water any rainfall or irrigation amounts and subtracting evapotranspiration and losses due to deep percolation and runoff. Evapotranspiration is calculated in component parts; that is, evaporation from the plant and evaporation from the soil are calculated separately. The daily value of the coefficient WATSCO is also assigned in this submodel. WATSCO is functionally related to two soil parameters, current soil water (SW) and upper limit of soil water (UL), as shown in Figure 10. WATSCO is used in submodel SYNTH which calculates plant dry matter production.

PHOTO determines the intercepted photosynthetically active radiation (PAR) and potential photosynthesis for the current day. Intercepted PAR is calculated on an hourly basis using a Beer's Law relationship.

SYNTH converts the potential photosynthesis into dry weight. SYNTH uses the water coefficient WATSCO and a temperature coefficient, TEMPCO, determined in SYNTH, to reduce dry matter production due to unfavorable temperatures and insufficient soil water. SYNTH also estimates night respiration losses before the final daily increase in plant dry weight is determined.

GROW is the submodel that determines the partitioning of dry matter production to the various plant organs based on the stage of growth of the grain sorghum. Plant organs include the root, leaves, culm, head and grain.

Model Validation

The forerunner of SORGF, introduced by Arkin et al.

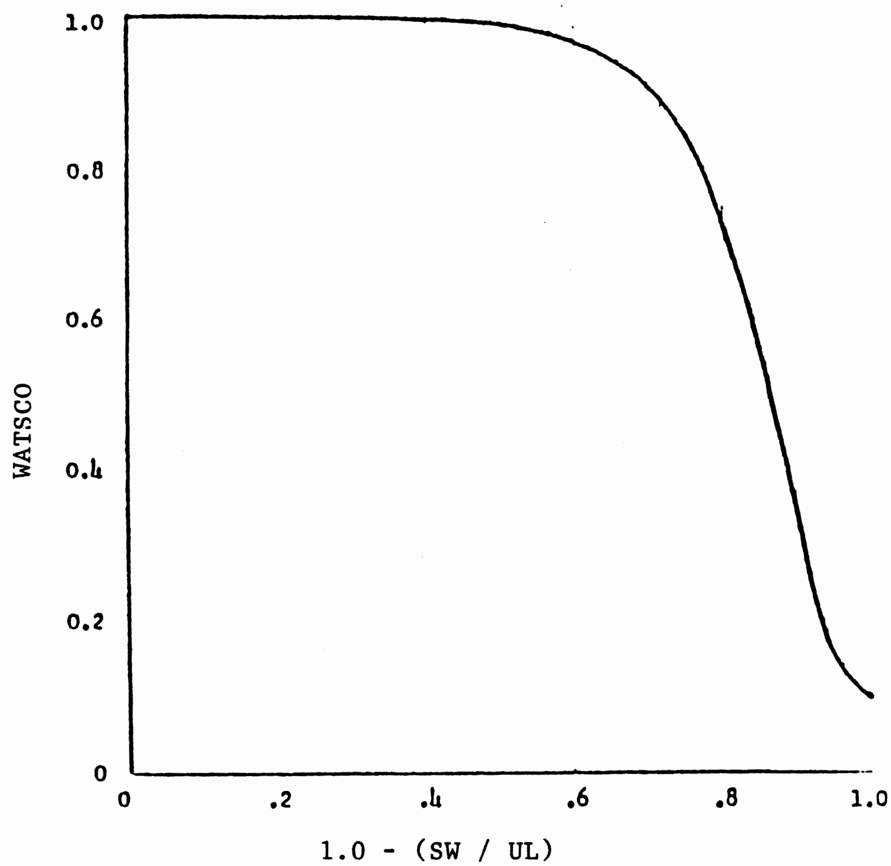

Figure 10. Crop Growth Coefficient, WATSCO, as a Function of Soil Water Content (Maas and Arkin, 1978)

(1976), was noted at its stage of development to have simulated with relative accuracy plant dry matter accumulation. They also indicated the model was sensitive to many production factors such as row spacing, plant population, different hybrids, ambient temperatures, solar radiation and available soil water. Maas and Arkin (1980) performed a sensitivity analysis of SORGF to determine the model response to changes in values of important system variables. The resulting responses were found to be consistent with the current understanding of plant-environment relationships. Harris (1981) used SORGF to derive daily growth of grain sorghum and evaluate the effects of various irrigation decision strategies in the Oklahoma Panhandle. Harris compared the results of 23 years of simulated grain sorghum yields under dryland and contemporary irrigation scenarios to a benchmark yield study by Gray et al. (1979). The results compared favorably. Agronomic experts at Oklahoma State University and the Blackland Conservation Research Center at Temple, Texas also judged the results to be favorable.

Hornbaker (1985) developed additional submodels for the SORGF model to derive optimal irrigation schedules under varying fuel prices, irrigation efficiencies, and market prices. Hornbaker also modified the SORGF software for microcomputer usage. He relied heavily on the validation work of Harris (1981) and Maas and Arkin (1978) but did complete an extensive verification of the SORGF model conversion to microcomputer.

Ham (1986) developed a new algorithm for SORGF to allow for non-homogeneous application of irrigation water. The results indicated that SORGF made reasonably good estimates of changes in the soil water balance over the growing season under both conditions of homogeneous and non-homogeneous irrigation applications. Simulation of grain yield was not a major focus of this study; however comparisons of simulated versus observed yields were presented and are shown in Table XIII.

Tsegaye (1986) concluded in his analysis of the actual field data that the non-homogeneous applications produced a higher yield than did the homogeneous applications for a given amount of applied water. Ham's simulated data showed no appreciable differences within a given year but the simulated yields for 1984 were greater than for 1985, which is consistent with observed data, and simulated yields were within 18% of the observed yields for all treatments. The feedback option was not used during these simulation trials. The irrigation treatments in this study kept the grain sorghum relatively well watered.

Dryland yield data were available from check plots of a wide-spaced furrow and diking study at Goodwell in 1984 and 1985 (Tsegaye, 1986). The observed and simulated yields are shown in Table XIV. While simulated and observed yields were not well matched in either year, the model predicted yields were both above and below the observed yields. Also

TABLE XIII

SIMULATED AND OBSERVED GRAIN SORGHUM YIELDS FOR ALL TREATMENTS FOR THE 1984 AND 1985 GROWING SEASON AT GOODWELL, OK.

Year	EFI[1] Yield				WSFI[2] Yield			
	Sim.	Obs.	Irrigation Amt.	Irrigation Freq.	Sim.	Obs.	Irrigation Amt.	Irrigation Freq.
	kg/ha	kg/ha	cm	days	kg/ha	kg/ha	cm	days
1984	6410	7340	37	14	6409	7360	37	7
1984	6398	6410	21	21	6397	7070	26	10.5
1985	6241	6510	37	14	6240	6930	33	7
1985	6225	5270	22	21	6214	6250	21	10.5

[1] EFI: Every Furrow Irrigation (homogeneous irrigation application)

[2] WSFI: Wide Spaced Furrow Irrigation (non-homogeneous irrigation application)

Source: Ham, 1986

TABLE XIV

SIMULATED AND OBSERVED GRAIN SORGHUM YIELDS FOR GOODWELL, OK.

Year	Dryland Yield		Soil-Water-Not-Limiting
	Simulated	Observed	Simulated Yield
	kg/ha	kg/ha	kg/ha
1984	3395	2120	6410
1985	3484	4264	6243

shown is a simulated yield for when soil water was not limiting (held at its upper limit throughout the simulations), which illustrates the sensitivity of SORGF to soil water. Other parameters were identical between years except for those related to climatic inputs and planting data.

An irrigation scheduling study by Lamm and Rogers (Lawless et al., 1985) involved multiplying the estimated evapotranspiration amount by factors ranging from 1.4 to 0.4 and using this information to calculate soil water depletion. Each of the treatments was watered individually and received an application amount equal to the predicted soil water depletion. These data were collected near Colby in northwest Kansas, approximately 320 km (200 miles) north of the Goodwell study site. No modifications were made to SORGF except for the usual input parameters.

SORGF simulated yields, observed yields, and total irrigation application amounts are shown in Table XV. Figures 11, 12, and 13 are graphical representations of simulated versus observed yields. These figures generally reflect the expected yield versus water use relationship. In this case yield is plotted against irrigation amount rather than total water use. Like most crops, grain sorghum exhibits greater yield response to water at low levels of water use than at high water use levels. Yield can even be adversely affected if excessive water inhibits growth processes due to water logging, nutrient leaching or other

TABLE XV

SIMULATED AND OBSERVED YIELD OF GRAIN SORGHUM FOR VARIOUS IRRIGATION TREATMENTS AT COLBY, KS.

Irrigation Treatment	Simulated Yield			Observed Yield			Irrigation Applied		
	kg/ha			kg/ha			cm		
	1982	1984	1985	1982	1984	1985	1982	1984	1985
1.4 ET	4377	8808	7656	6164	8229	6961	20.56	58.78	51.06
1.2 ET	4374	8808	7653	5888	7733	7168	17.36	49.69	33.82
1.0 ET	4369	8803	7653	5988	8141	7149	17.22	36.40	26.85
0.8 ET	4290	8634	7605	5743	7890	6860	11.16	25.43	17.22
0.6 ET	4172	7832	4816	5291	7093	7036	8.04	19.93	6.48
0.4	2699	5868	3448	5335	6402	6252	0.00	8.03	0.00

Rainfall Amounts: 1982 19.19 cm
1984 8.97 cm
1985 14.71 cm

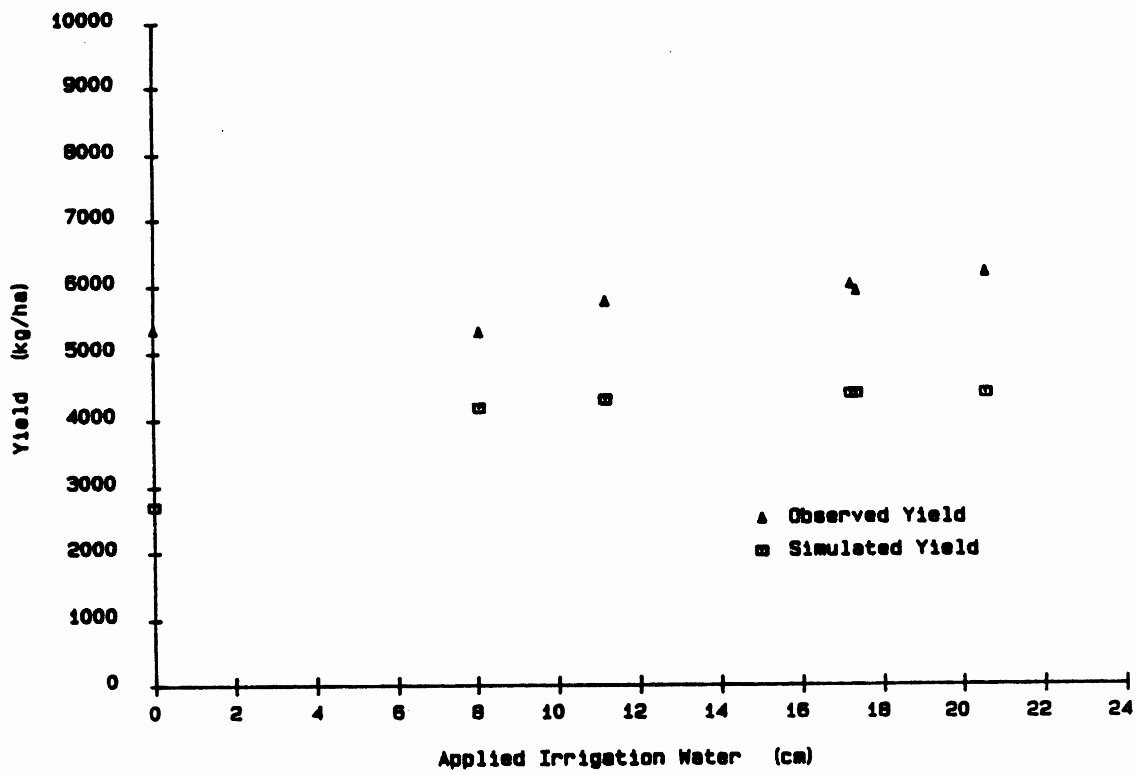

Figure 11. 1982 Simulated and Observed Grain Sorghum Yields Versus Applied Irrigation Water at Colby, KS.

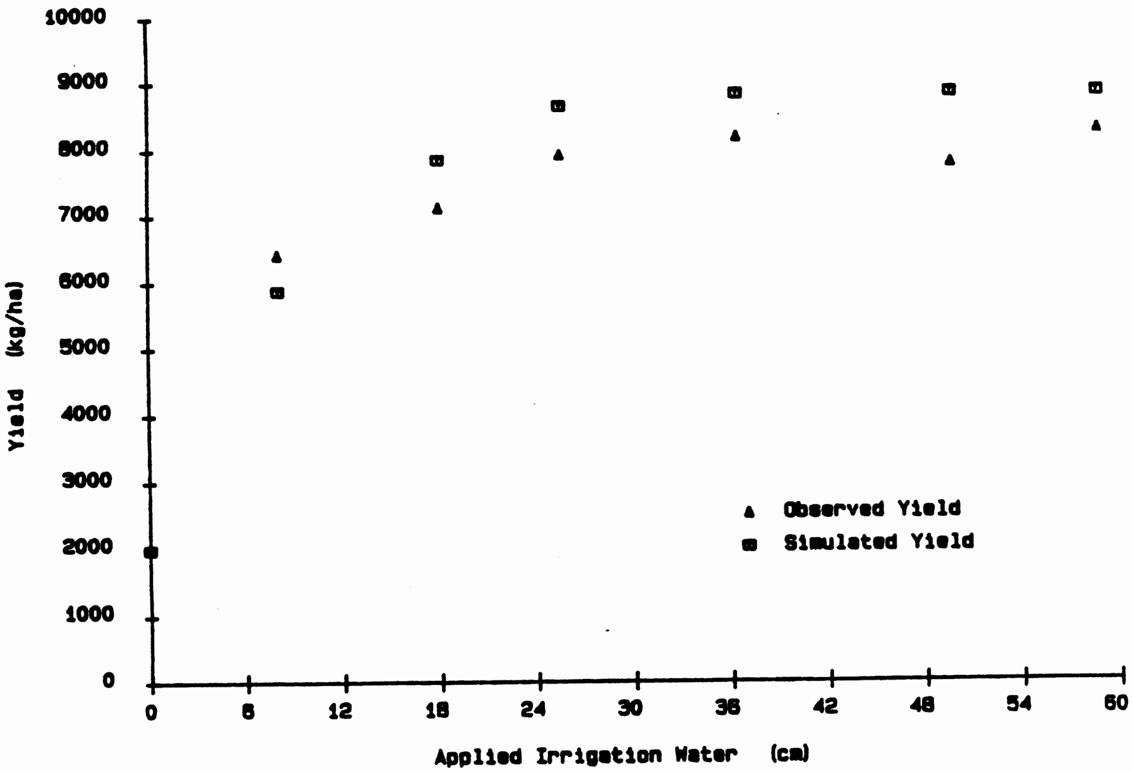

Figure 12. 1984 Simulated and Observed Grain Sorghum Yields Versus Applied Irrigation Water at Colby, KS.

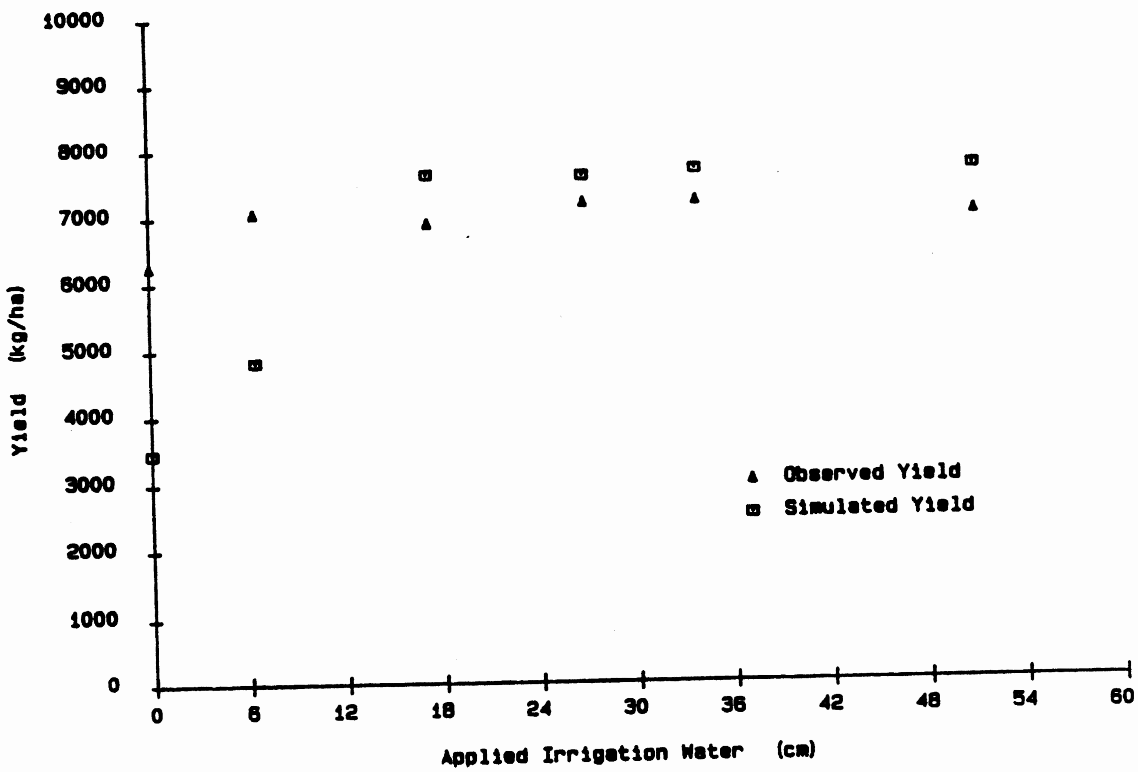

Figure 13. 1985 Simulated and Observed Grain Sorghum Yields Versus Applied Irrigation Water at Colby, KS.

such factors.

Figure 14 compares simulated yield to observed yield for the three years of the study. The 1984 and 1985 data indicate that the SORGF predicted yields matched field observations fairly well, although in 1985 the lower yields were underpredicted. For the model predictions shown, the upper limit (UL) of soil water was set at 25 cm for the root zone. This study was conducted on deep, well-drained, loessial Keith silt that holds approximately 25 cm of soil water in the soil profile (Bidwell et al., 1980). Some soil water observations exceeded this amount, and a more exact estimate of UL might have improved the model's predictions considerably since additional available soil water for the low or no irrigation treatments affects yields much more significantly than additional available soil water for well watered treatments. When low soil water conditions are occurring even small amounts of additional water can have a significant effect on yield since WATSCO (Figure 10) has a definite break point after which any additional loss (or gain) of soil water greatly alters the WATSCO value. For example, in 1985 using a UL value of 27.5 cm, the yield of the 0.4 treatment was predicted to be 7633 kg/ha, which is greater than the observed value and more than double the yield predicted using a UL of 25 cm. This effect was not as pronounced in 1984, when even the 0.4 treatment received some irrigation.

The 1982 results are troublesome, in that SORGF greatly

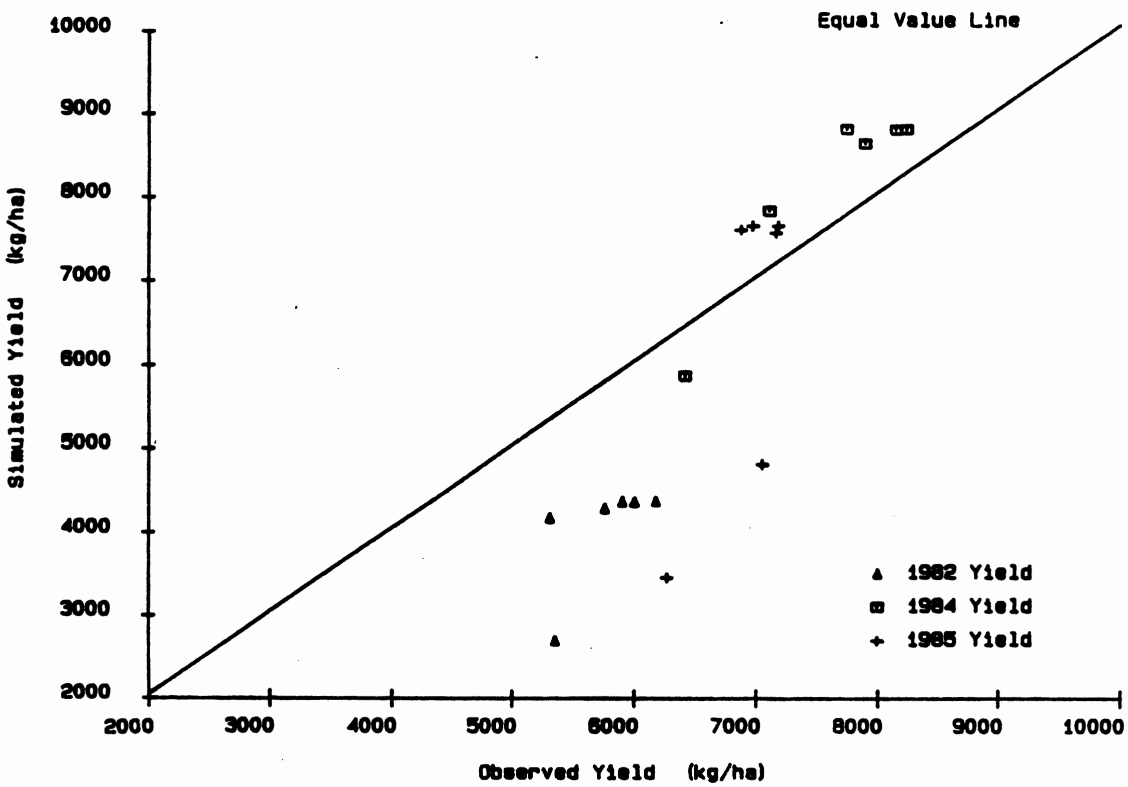

Figure 14. Simulated and Observed Grain Sorghum Yields for 1982, 1984, and 1985 at Colby, KS.

underpredicted the observed yields at all irrigation treatment levels. The crop in 1982 was planted 25 days later in the growing season than the 1984 and 1985 crops, which initially led to speculation that the underpredictions of yield may have been the result of underprediction of energy available to drive the evapotranspiration process. To estimate potential evaporation, SORGF uses a Priestley-Taylor type expression that does not include use of a wind function. This can lead to serious underprediction of evaporative demand when advection is a factor. However, while plant transpiration is strongly correlated with plant photosynthate production, the model does not use the estimate of evaporative demand to directly calculate photosynthate production. This demand is used in the SOLWAT submodel to estimate losses in determining the soil water balance. Plant photosynthesis is based on the submodel PHOTO which uses solar radiation data to estimate energy availability for photosynthesis. Soil water levels affect photosynthesis production through the WATSCO coefficient.

Two other soil parameters are used in SOLWAT to calculate the soil water balance. The coefficients are the upper limit of Stage 1 cumulative evaporation, U, and the Stage 2 evaporation rate coefficient, B. These coefficients affect the soil water balance, which in turn affects the coefficient WATSCO. Ham (1986) made an estimate of U for the Richfield clay loam soil of the Goodwell study site and used a linear relationship developed from data by Ritchie

(1972) to determine B.

The values summarized by Ritchie (1972) and developed by Ham (1986) are shown in Table XVI. Richfield clay loam soil is found in Thomas County, Kansas, the location of the Colby study. The Keith series of soils, on which the Colby irrigation study was conducted, are similar to Richfield soil and are commonly adjacent to each other in their position on the landscape (USDA, SCS, 1980). They have similar available water holding capacities, but the Richfield soils have slightly lower permeability than Keith soils (USDA, SCS, 1983), which place them in different irrigation design groups. Trial simulations for U values above and below the U used by Ham, along with the corresponding B coefficient, for three years at Colby showed relatively small yield effects, again apparently dampened by the WATSCO coefficient (especially for well watered treatments). However alteration of the coefficients did affect the allocation between soil evaporation and plant evaporation, and the soil water balance predictions. Based on available information and the sensitivity trials the soil evaporation coefficients currently used in SORGF seemed to be the best available. This conclusion however still does not explain the large underprediction of yield for 1982 at the Colby study site. The late planting of the 1982 crop leads to speculation that possibly one or more empirically based growth functions may be outside their limits of calibration. Field trials at the Colby site with varying

TABLE XVI

UPPER LIMIT OF STAGE 1 CUMULATIVE EVAPORATION, U, AND STAGE 2 EVAPORATION COEFFICIENT, B, FOR FIVE SOIL TYPES

Soil Type	U cm	B $cm/day^{1/2}$	Reference
Adelanto clay loam	1.2	0.508	van Bavel et al., 1968
Yolo loam	0.9	0.404	LaRue et al., 1968
Houston black clay	0.6	0.350	Ritchie et al., 1972
Plainfield sand	0.6	0.344	Black et al., 1969
Richfield clay loam	1.2	0.51	Ham, 1986

planting dates could support or reject this hypothesis.

The final conclusion concerning the validity of SORGF is that it is a sensitive and representative model of a growing grain sorghum crop, capable of representing yields in a general sense for large scale economic studies and of matching observed yields when calibrated for specific field conditions.

Model Modifications

Ham's (1986) version of SORGF was modified for this study by incorporating submodels into the program to make yield projections based on historical weather data. This revised version's flow diagram is shown in Figure 15. The addition to SORGF begins at the end of a day's growth simulation. After leaving the maturity decision block with a "No" answer, the program then enters a decision block as to whether a yield projection should be made. The decision block has two criteria. The first involves a check on whether a previous irrigation application is complete, since a second irrigation cannot be applied until the first has been completed. The second criterion checks the soil water status and does not allow a yield projection to occur if the soil water level is greater than a critical level. Preliminary runs showed no irrigation was scheduled when over half the available soil water remained, so this limit was placed into the program simply to speed computation of schedules by limiting unnecessary yield projections.

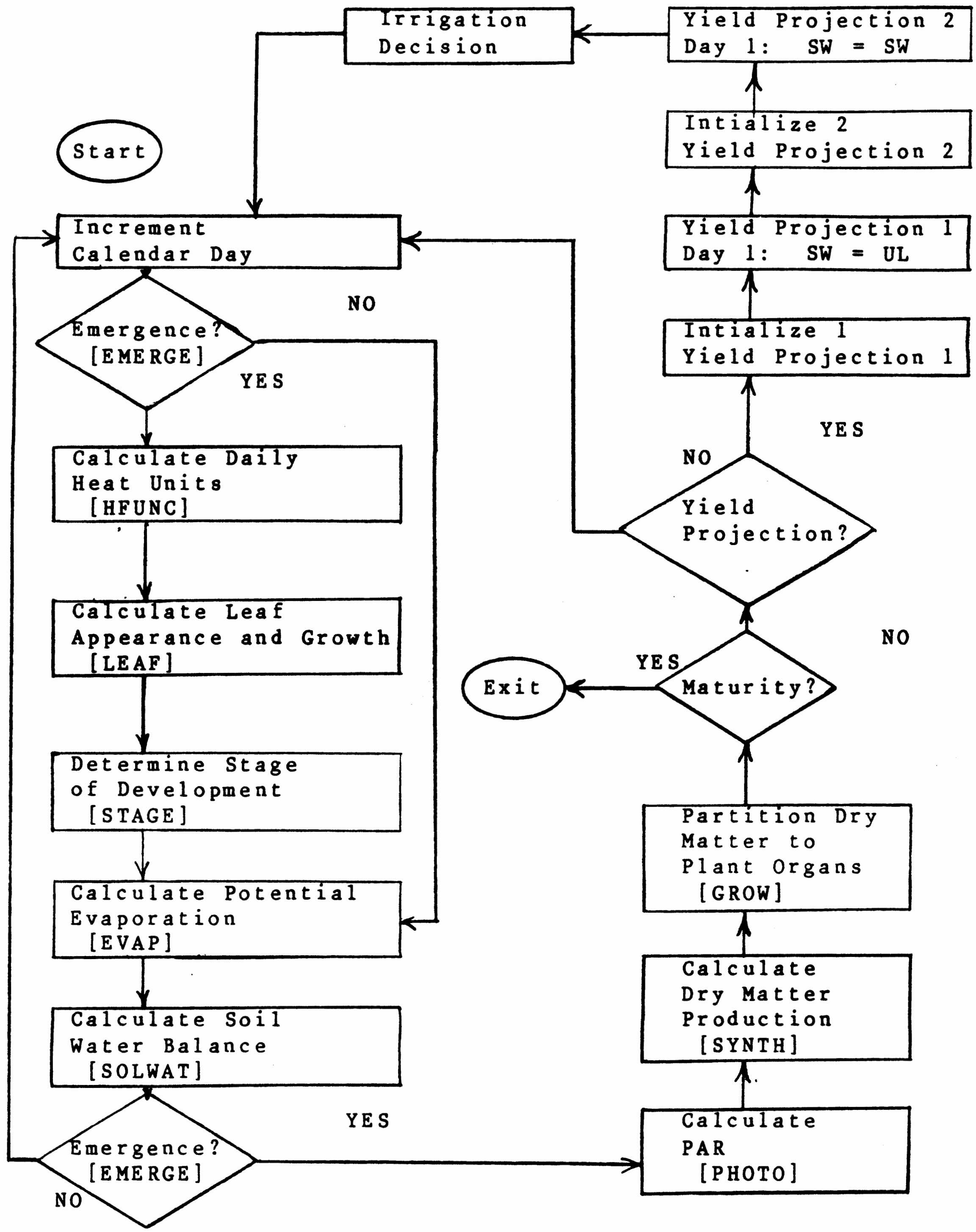

Figure 15. Simplified Flow Diagram of SORGF With Risk Analysis Loop for Irrigation Decision-Making

Once the daily criteria for making a yield projection are satisfied, an initialization procedure reassigns the values of all program variables to new variable names. New variable names are used to preserve the current variable values for use after a yield projection is made. The yield projection procedures are essentially those in the current SORGF version and follow the same flow as shown previously in Figure 9, with the exception that daily soil water levels are always reset to the value of 75% of the upper limit for soil water.

The yield projections are made using the historical average for maximum and minimum temperatures for Goodwell, Oklahoma. Long-term solar radiation values are not available at Goodwell, requiring solar radiation data (23 year record) from Dodge City, Kansas to be used as an estimate for Goodwell conditions. This was also the procedure used by Harris (1981) and Hornbaker (1985).

The difference in yield projection 1 and yield projection 2 lies in the first day's soil water. Projection 1 is the yield based on the first day of the projection having a soil water value equal to the current soil water level and then all remaining days with the soil water set to 75% of UL. Projection 2 is the yield based on all days' soil water being set at 75% of UL. The difference in these values is the estimated yield loss for a one day delay in applying irrigation water. This loss is carried forward into the next module where the decision on whether or not to apply irrigation water is made.

The yield projections could be made based on any constant level of soil water as the program is currently designed. Several options were investigated which included projecting yields with soil water equal to the current day soil water value plus net irrigation application, and projecting yields using various fixed percentages of the upper limit of soil water. This first option was rejected after trial simulations showed extreme yield reductions result from delays in the irrigation schedule. If a small net irrigation amount is used, such as would be the case in many center pivot applications, the projected yield difference between yield projection 1 and yield projection 2 is reduced. Previously the functional relationship between WATSCO and soil water was shown in Figure 10. This figure indicates that if large soil water depletions are occurring, a small irrigation application may not be sufficient to restore the soil water to a level that would result in a recovery of WATSCO. Therefore the yield projection difference would be based on two reduced yield levels, which minimizes the yield difference and results in an increased likelihood of irrigation delay. Selecting a procedure that minimizes the projected yield difference is building a bias into the cost-loss decision-making process, as an accurate representation of the true potential loss is not reflected.

Maintaining available soil water above the 50% level has often been used in irrigation scheduling guidelines for field crops in the High Plains area. At this level of soil water, WATSCO is approaching its upper limit. However using the 50% criterion would still mean that irrigation decisions would be based on reduced potential yield estimates. Likewise projecting yield differences at the upper limit of soil water may also be arguably unrealistic since maintenance of soil water at the maximum is highly unlikely for a field crop particularly in light of irrigation system capacities.

Yield projections were made using a soil water level at 75% of UL to represent an average soil water condition for a contemporarily irrigated grain sorghum crop. Irrigation systems, with few exceptions, require an interval of at least several days to apply the net irrigation application. Even if the net application rate is meeting the crop water demand, during the irrigation interval the soil water level in the field will vary from the beginning soil water value to some lower value dependent on the crop water use rate. If the system capacity exactly meets the crop water use rate, the soil water will fluctuate between these two values and the average soil water will be the beginning soil water value minus one half the net irrigation application (system capacity equals crop demand). The irrigation system capacity for this study (detailed later) exceeds the average seasonal crop demand and therefore if continuous irrigation was practiced, the average soil water level would gradually be increased until it reached nearly its upper limit.

Shorter irrigation intervals result in less soil water fluctuation than longer irrigation intervals. Projecting potential yield at 75% of UL for this study appears to be a reasonable estimate, when considering the average irrigation interval of the 7.5 cm and 2.5 cm net irrigation applications selected for investigation and that the beginning soil water is at two-thirds of UL. In this particular instance, due to the nature of the functional relationship of WATSCO and soil water for grain sorghum, the difference between a selection at UL or 75% of UL will have little significance. However selection of the soil water level for yield projection for other crops may have more important implications and should be given proper consideration.

The irrigation time interval also affects the yield of plants based on their position within the field, the extremes of which are the first and last plant to receive water. To account for the yield difference between the first and last plants in the field, yields for both are modeled. First plant irrigation dates are established by the irrigation scheduling criteria (described later), and the date of the last plant irrigation can then be calculated. These dates are entered into the model to determine last plant yield. The two yields are averaged to make an estimate of the average field yield.

SORGF was also modified to allow the final irrigation amount to be reduced in proportion to the days remaining until physiological maturity of the crop. The date of physiological maturity is projected each time a yield projection is made. Using this information as part of the scheduling process is a simplistic approach to mimic an irrigation manager's adjustment of the final irrigation. This prevents SORGF from initiating an irrigation requiring many days to apply when only a few days remain until physiological maturity. This proportional amount of application does not return WATSCO to the same level as the original net application amount but does prevent excessive yield reductions. The resulting yields are similar to fully irrigated yields without the entire expense of the full irrigation being charged.

Irrigation Scheduling Criteria

The calculated risk analysis concept, incorporating the cost/loss ratio, will be evaluated by comparing it to existing methods of scheduling irrigations. Harris (1981) defined contemporary irrigation practices for the Panhandle of Oklahoma as applying 61 cm (24 inches) of irrigation water per year regardless of climatic conditions or soil water availability. He examined a variety of irrigation schedules using stochastic efficiency and optimal control procedures. These irrigation scenarios include:

1) No delay scenario; irrigation is initiated only when the extractable soil water ratio is less than or equal to 45%. Extractable soil water is the water available to the plant and is the

difference between field capacity and permanent wilting point.

2) Growth stage delay irrigations; irrigations are initiated as in the no delay scenario except during specified stages of growth, when no irrigation is applied.

3) Days before soil water ratio irrigation; irrigations are initiated with the objective that no plant should experience water stress, i.e., experience stress below a given extractable soil water ratio.

Harris identified irrigation scenarios which resulted in increased net returns and water savings over contemporary irrigation practices. Efficient irrigation scenarios selected from Harris for comparison to schedules generated using risk analysis are: (1) irrigations initiated at or below an extractable soil water ratio of 45%, and (2) three scenarios with the 45% limit and irrigation withheld during either growth stage 1, stage 3, or a combination of growth stages 1 and 3. These represent the best options from the scenario combinations described by Harris.

The calculated risk concept, as previously described, is as follows:

If:	Then:
$P > C/L$	Protect
$P = C/L$	Either course
$P < C/L$	Do not protect

where:

P = the probability of loss occurring;

C = the cost of protective measures;

L = the loss incurred should no protective action be taken.

The probability of loss occurrence is one minus the probability of rainfall for that particular day as defined by the various methods discussed previously. The loss is the projected yield difference (D), discussed previously, times a crop price (CP). The cost (C) is the operational expense associated with providing irrigation water on a daily basis. The fact that the cost and loss terms are used in a ratio makes the terms somewhat normalized or relative to each other. For example, doubling both C and CP would result in the same C/L ratio. The cost of irrigation was kept constant throughout the simulation trial and the crop price varied to acheive the three C/L ratios. The irrigation schedule resulting from a given ratio is the same regardless of how the level of the ratio occurred. The crop price will affect the magnitude of the final return for each of the schedules, but not neccessarily the relative relationship between the schedules.

The average price for grain sorghum currently used by the OSU Agricultural Economics Department (Mapp, 1987) in farm budgets is \$0.066/kg (\$3.00/cwt). Natural gas is the predominant energy source of the region (Kizer, 1985) and its cost currently ranges from $\$0.01/m^3$ to $\$0.16/m^3$ with the average cost being closer to the higher figure (Kizer, 1987). A representative natural gas price was selected to be \$0.12/m^3 (\$3.40/MCF). A typical pumping depth and discharge capacity for wells in the region are 80 m and 65 L/s, respectively.

The operating costs for irrigation, considering only fuel consumption, were calculated by first determining the total expense for fuel for a given net application. This total expense was then divided by the number of hectares in the field and then by the number of days required to complete irrigation over the entire field. This makes the irrigation cost units identical to the units of measure for projected yield loss times crop price. This also makes the irrigation cost independent of application amount, since altering application depth changes both the time to complete an irrigation and the number of hectares irrigated per day.

Typical surface irrigation system costs can be estimated by assuming an irrigation application efficiency of 75%, a 10 cm net irrigation application, a 62.7 ha field, and a pressure head requirement of 14 m. The irrigation pumping plant was also assumed to perform at the Nebraska Performance Criteria (Schleusener and Sulek, 1959) for natural gas which is 1.62 kw-hr of energy delivered to the water for every m^3 of natural gas burned. The operating cost, using these assumptions, was calculated to be \$1.69/ha-day. Similarly, for a typical center pivot the costs were \$1.80/ha-day, using the assumptions that the pivot was applying 2.5 cm of net irrigation water at 80% application efficiency on a 53.5 ha field while operating at 30.5 m pressure and 50.5 L/s discharge. The total discharge capacity for a center pivot irrigation system is generally less then that of a surface irrigation system, largely due to smaller irrigated area per system, although irrigation system efficiency (generally higher for a pivot system) and design considerations, such as pressure losses along the pivot distribution pipe, play a role. A representative cost of irrigation was selected to be \$1.75/ha-day, regardless of the system type.

The irrigation scheduling decision model will then be based on a ratio of these cost and loss values in the C/L risk analysis model. The loss will be the representative price (\$0.066/kg) times the yield loss difference projected on a daily basis by the SORGF simulation model. This can be represented as follows:

$$\frac{C}{L} = \frac{\$1.75/\text{ha-day}}{\$0.066/\text{kg} * YL} = \frac{26.52}{YL}$$

where:

YL = projected yield loss in kg/ha-day.

Two other C/L ratios will also be used in determining irrigation schedules. They will be ratios based on a high irrigation cost to crop price ratio and a low irrigation cost to crop price ratio, as shown in Table XVII. The possible scenarios listed in Table XVII only partially represent the combinations of crop prices and irrigation

TABLE XVII

THE C/L RISK ANALYSIS RATIO USED FOR IRRIGATION SCHEDULING

Value of C/L Ratio	Possible Scenario for Occurrence
$\frac{26.52}{YL}$	"Typical" or base ratio Crop price = \$0.066/kg Irrigation cost = \$1.75/ha-day YL = yield loss in kg/ha-day
$\frac{13.26}{YL}$	Crop price doubles or Irrigation cost decreases by half, or equivalent combination
$\frac{53.03}{YL}$	Crop price decreases by half or Irrigation cost doubles, or equivalent combination

costs that could be represented by those particular C/L ratios. The typical C/L ratio actually represents a range of equal percentage increases and decreases of crop price and irrigation cost. The two other ratios can be achieved as noted in Table XVII or, for example, the C/L ratio of 53.03/YL can also be achieved by a 25% reduction in crop price and a 50% increase in irrigation cost. Irrigation cost changes can reflect changes in either fuel price or pumping plant efficiency, or both.

Each of these three C/L ratios is incorporated into the irrigation decision submodel of SORGF and used to produce irrigation schedules for each of the various methods of defining the rainfall probability.

The C/L ratios developed are based on typical irrigation systems for the region. Once a decision to irrigate is made an application amount and the duration of the irrigation event must be known to allow the proper soil water level to be calculated and to allow realistic simulation. Two levels of net irrigation amount are used to examine its effect on the schedule. These net irrigation amounts are 7.5 cm and 2.5 cm, with respective application durations of 12 days and 4 days, based on the typical surface and center pivot irrigation systems previously described.

Planting date is also required by SORGF. Planting date is a variable which is affected each year by many factors, an important one of which is climatic conditions. Actual planting dates for 1984 through 1987 are known for grain sorghum studies at the Panhandle Research Station and these dates are used in the simulation trials as dates representative of the area.

The beginning level of soil water for each of the years is set at 17.27 cm, which is two-thirds of the value of the upper limit of soil water. Beginning soil water levels would be extremely variable between fields and between years. However, practically speaking, planting could not occur if the soil water was at the upper limit. Extremely low soil water levels would be unlikely since preseason irrigation applications could be made. In addition a study by Lamm and Rogers (1985) would suggest the probability of low soil water at planting would be low even without off-season irrigation.

The C/L decision-making process involves making a daily decision about which course of action to follow for the particular situation being investigated. Unfortunately the loss preventing action for crop production (i.e., irrigation) is a multi-day function, which complicates the decision-making process. It has already been noted that a yield difference exists between the first watered and the last watered plant in the irrigation interval, and that the yield of the field is represented by the average of these two yields. This difference in yield has an effect on the C/L decision-making process. The decision for beginning an irrigation would depend upon which plant was being used in the model. Using the C/L ratio method with SORGF results in low soil water levels before irrigation is initiated and may cause the last plant to experience extremely low and yield limiting soil water levels before receiving irrigation, particularly when high net irrigation applications are being used. This means the C/L decision-making process is not receiving correct information about the true loss associated with a particular irrigation date. This problem was addressed by making an estimate of soil water at either the mid-point or end of the irrigation interval. The soil water value was projected by assuming a continuation of the current ET demand into the future. The daily ET demand for half (or all) the number of days to complete the irrigation, prior to and including the current day, are summed and then subtracted from the current soil water. This soil water value then enters into the yield projection cycles described previously. This transfers the yield loss projection to either the mid-point or to the last day of the irrigation interval. Both of these soil water projection methods are utilized.

The study site selected is in a semi-arid region. In an attempt to increase understanding of the usefulness of the C/L ratio in more humid environments, the weather record previously described was altered by doubling each rainfall amount, although this does not account for differences in rainfall frequencies between climatic groups. Only stage of growth (Harris, 1981) and middle and last plant scenarios for professional forecasts were included in this aspect of the investigation.

The described combinations of input variables are used to develop the various irrigation schedules using both the C/L ratio decision-making process and the selected irrigation schedules from Harris (1981). Statistical analysis of economic returns and irrigation application amounts are used to compare the various schedules. Trends of other production parameters are noted.

CHAPTER IV

RESULTS AND DISCUSSION

A grain sorghum crop growth simulation model was combined with a calculated risk decision-making process to determine optimal irrigation schedules. The calculated risk concept used is as follows:

If:	Then:
$P > C/L$	Protect
$P = C/L$	Either course
$P < C/L$	Do not protect

where:

P = the probability of the loss occurring,

C = the cost of protective measures,

L = the loss incurred should no protective action be taken.

In this case:

P = the probability of no rainfall,

C = the daily cost of irrigation,

L = the daily loss in value of crop yield due to insufficient soil water.

The probability of a loss due to no rainfall was calculated by subtracting the probability of rainfall from one. Three general classes of estimating rainfall probability were examined, which were: (1) climatological forecasts, (2) probabilistic forecasts and derivatives thereof, and (3) perfect forecast, where rainfall records were examined to generate either a 100% probability (rainfall occurred) or a 0% probability (no rainfall occurred). Rainfall probability estimates using these three forecast classes were prepared for the 1984 through 1987 growing seasons.

Four irrigation scenarios were selected from Harris (1981) to represent contemporary improved irrigation practices. These scenarios allow irrigation to begin only when extractable soil water is less than 45%. This is the only criterion for one scenario. The other scenarios have stage of growth restrictions, where irrigation water is withheld regardless of soil water status.

All simulations were conducted twice. Since irrigation applications are not instantaneous and are associated with an application time interval, soil water levels were projected ahead, using current daily evapotranspiration (ET) as an estimate of future ET. ET for each day prior to the projection date, was summed for either one-half the number of days of the irrigation interval (middle plant), or for the total number of days of the irrigation interval (last plant). These sums were subtracted from the current soil water level. The new soil water value was then entered into the yield estimating procedure that ultimately determined whether irrigation was initiated or not. This was done to minimize yield differences between the first and last plants in the field receiving water. No adjustments were made for the contemporary irrigation scenarios, although like the C/L simulations, yields used for analysis are the average of first and last watered plants.

Fourteen different irrigation scheduling methods were used during the simulation trials. Table XVIII was prepared to aid in identification of the scheduling methods in future tables.

Tables XIX through XXI give the average results for three levels of C/L ratios for the middle plant irrigation scenario. The results of the growth stage irrigation schedules are shown in each table although all variables with the exception of return are constant between tables. Tables XXII through XXIV give the last plant results for the three C/L ratios used. Data for individual years for both middle and last plants are shown in Tables LXV through LXVIII in Appendix C.

Each table has information regarding water use efficiency (WUE) measures for total net irrigation water applied, ET (a measure of total water use from soil water, rainfall, and irrigation), and plant transpiration, EP. Total net irrigation is referred to as total irrigation application or irrigation water application for the remainder of the text. Economic return is the primary concern for most agricultural producers. Net return is often defined as return to land, labor and management.

TABLE XVIII

ABBREVIATIONS USED FOR IDENTIFYING METHOD OF IRRIGATION SCHEDULE

Method Number	Abbreviation	Method of Scheduling Irrigation
1	GS0	No growth stage restrictions (from Harris, 1981)
2	GS1	Irrigation withheld growth stage 1 (from Harris, 1981)
3	GS3	Irrigation withheld growth stage 3 (from Harris, 1981)
4	GS13	Irrigation withheld growth stage 1 & 3 (from Harris, 1981)
5	DAILY	Daily climatological probability
6	DAILYCV	Daily climatological probability for rainfall $\geq$ .635 cm
7	COND	Conditional daily climatological probability
8	CONDCV	Conditional daily climatological probability for rainfall $\geq$ .635 cm
9	FCST	Probabilistic forecast
10	COMFCST	Comparative probabilistic forecast
11	CONDFCST	Conditional comparative probabilistic forecast
12	COMFCV	Comparative probabilistic forecast for rainfall $\geq$ .635 cm
13	CONDFCV	Conditional comparative probabilistic forecast for rainfall $\geq$ .635 cm
14	PERFECT	Perfect forecast

TABLE XIX

AVERAGE RESULTS OF 1984 THROUGH 1987 CROP GROWTH SIMULATION TRIALS FOR LOW IRRIGATION COST/HIGH CROP VALUE RATIO FOR MIDDLE PLANT IRRIGATION SCENARIO

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	24.22	5942	247.4	140.4	225.2	716.52
GS0	2.5	22.81	5946	263.3	140.7	225.9	721.05
	Ave	23.51	5944	255.4	140.5	225.6	718.79
	7.5	24.22	5940	247.4	140.4	225.3	716.23
GS1	2.5	22.81	5953	263.6	140.9	226.3	721.93
	Ave	23.51	5946	255.5	140.7	225.8	719.08
	7.5	24.22	5843	243.1	138.6	222.4	703.47
GS3	2.5	22.03	5808	267.4	138.6	223.4	705.02
	Ave	23.12	5826	255.3	138.6	222.9	704.25
	7.5	24.22	5843	243.1	138.6	222.5	703.40
GS13	2.5	21.25	5844	279.4	139.5	225.0	711.89
	Ave	22.73	5843	261.3	139.1	223.7	707.65
	7.5	20.62	5635	277.3	135.9	220.7	686.09
DAILY	2.5	16.25	5533	344.5	137.6	227.8	684.86
	Ave	18.43	5584	310.9	136.8	224.3	685.47
	7.5	21.87	5661	262.8	136.4	221.4	685.93
DAILYCV	2.5	16.25	5585	347.7	138.1	227.8	691.72
	Ave	19.06	5623	305.3	137.3	224.6	688.82
	7.5	16.40	5320	328.8	131.8	217.8	656.33
COND	2.5	13.90	5320	387.9	135.6	227.9	663.39
	Ave	15.15	5320	358.4	133.7	222.8	659.86
	7.5	16.56	5395	331.5	132.5	217.9	665.82
CONDCV	2.5	14.06	5344	385.3	134.8	225.6	666.08
	Ave	15.31	5370	358.4	133.6	221.7	665.95
	7.5	21.87	5647	262.2	136.0	220.4	684.15
FCST	2.5	16.25	5518	343.6	136.9	226.0	682.91
	Ave	19.06	5583	302.9	136.4	223.2	683.53

TABLE XIX (Continued)

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	16.40	5323	329.1	131.3	217.1	656.71
COMFCST	2.5	13.75	5271	390.2	134.5	226.5	657.27
	Ave	15.07	5297	359.6	132.9	221.8	656.99
	7.5	16.40	5315	328.5	131.8	218.3	655.60
CONDFCST	2.5	13.75	5264	389.2	134.6	226.7	656.40
	Ave	15.07	5290	358.8	133.2	222.5	656.00
	7.5	16.72	5412	330.3	132.6	217.8	667.56
COMFCV	2.5	14.53	5433	378.9	136.7	228.0	676.47
	Ave	15.62	5423	354.6	134.6	222.9	672.02
	7.5	16.56	5395	331.5	132.5	217.9	665.82
CONDFCV	2.5	13.90	5392	392.9	136.2	227.7	672.84
	Ave	15.23	5394	362.2	134.4	222.8	669.33
	7.5	22.03	5680	262.2	136.6	221.5	688.12
PERFECT	2.5	16.25	5617	349.6	138.6	228.2	695.93
	Ave	19.14	5649	305.9	137.6	224.8	692.02

TABLE XX

AVERAGE RESULTS OF 1984 THROUGH 1987 CROP GROWTH SIMULATION TRIALS FOR TYPICAL IRRIGATION COST/CROP VALUE RATIO FOR MIDDLE PLANT IRRIGATION SCENARIO

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ha	kg/ha-cm	kg/ha-cm	kg/ha-cm	$/ha
	7.5	24.22	5942	247.4	140.4	225.2	324.35
GS0	2.5	22.81	5946	263.3	140.7	225.9	328.59
	Ave	23.51	5944	255.4	140.6	225.6	326.47
	7.5	24.22	5940	247.4	140.9	225.3	324.20
GS1	2.5	22.81	5953	263.6	140.9	226.3	329.01
	Ave	23.51	5946	255.5	140.9	225.8	326.61
	7.5	24.22	5843	243.1	138.6	222.4	317.83
GS3	2.5	22.03	5808	267.4	138.6	223.4	321.66
	Ave	23.12	5826	255.3	138.6	222.9	319.75
	7.5	24.22	5843	243.1	138.6	222.5	317.79
GS13	2.5	21.25	5844	279.4	139.5	225.0	326.19
	Ave	22.73	5843	261.3	139.1	223.7	321.99
	7.5	15.15	4984	329.1	127.3	214.7	286.53
DAILY	2.5	11.87	4978	428.0	131.4	226.2	295.33
	Ave	13.51	4981	378.5	129.3	220.5	290.93
	7.5	18.59	5476	301.5	135.2	222.6	309.36
DAILYCV	2.5	13.75	5202	384.8	135.3	230.3	304.84
	Ave	16.17	5339	343.1	135.3	226.4	307.10
	7.5	13.59	4663	345.1	120.9	205.9	269.70
COND	2.5	10.93	4828	443.4	128.5	222.3	288.04
	Ave	12.26	4746	394.2	124.7	214.1	278.87
	7.5	14.37	4679	326.8	121.2	206.3	268.55
CONDCV	2.5	11.56	4946	437.2	130.8	225.4	294.06
	Ave	12.97	4813	382.0	126.0	215.9	281.31
	7.5	17.19	5495	325.9	134.4	220.5	314.56
FCST	2.5	12.50	5004	404.4	131.3	225.0	295.27
	Ave	14.84	5250	365.2	132.9	222.8	304.92

TABLE XX (Continued)

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	13.28	4654	355.2	120.8	205.7	269.95
COMFCST	2.5	10.93	4828	443.3	128.4	222.2	288.04
	Ave	12.11	4741	399.3	124.6	214.0	278.99
	7.5	13.59	4663	345.1	120.9	205.9	269.70
CONDFCST	2.5	10.78	4813	448.7	128.1	221.8	287.44
	Ave	12.18	4738	396.9	124.5	213.9	278.57
	7.5	14.53	4685	322.9	121.3	206.4	268.49
COMFCV	2.5	11.56	4946	437.2	130.8	225.4	294.06
	Ave	13.04	4815	380.1	126.1	215.9	281.27
	7.5	14.37	4679	326.8	121.2	206.3	268.55
CONDFCV	2.5	11.56	4946	437.2	130.8	225.4	294.06
	Ave	12.97	4812	382.0	126.0	215.9	281.30
	7.5	18.90	5221	300.9	135.1	220.9	311.41
PERFECT	2.5	13.90	5232	382.4	134.5	227.4	306.36
	Ave	16.40	5227	341.7	134.8	224.2	308.89

TABLE XXI

AVERAGE RESULTS OF 1984 THROUGH 1987 CROP GROWTH SIMULATION TRIALS FOR HIGH IRRIGATION COST/LOW CROP VALUE RATIO FOR MIDDLE PLANT IRRIGATION SCENARIO

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ha	kg/ha-cm	kg/ha-cm	kg/ha-cm	$/ha
	7.5	24.22	5942	247.4	140.4	225.2	128.26
GS0	2.5	22.81	5946	263.3	140.7	225.9	132.35
	Ave	23.51	5944	255.4	140.5	225.6	130.31
	7.5	24.22	5940	247.4	140.4	225.3	128.19
GS1	2.5	22.81	5953	263.6	140.9	226.3	132.57
	Ave	23.51	5946	255.5	140.7	225.8	130.38
	7.5	24.22	5843	243.1	138.6	222.4	125.00
GS3	2.5	22.03	5808	267.4	138.6	223.4	129.98
	Ave	23.12	5826	255.3	138.6	222.9	127.49
	7.5	24.22	5843	243.1	138.6	222.5	124.99
GS13	2.5	21.25	5844	279.4	139.5	225.0	133.34
	Ave	22.73	5843	261.3	139.1	223.7	129.16
	7.5	11.56	4437	395.4	117.8	205.0	114.05
DAILY	2.5	9.375	4325	476.4	118.3	208.7	116.47
	Ave	10.47	4381	435.9	118.1	206.9	115.26
	7.5	14.69	4689	319.1	121.4	206.4	113.60
DAILYCV	2.5	9.532	4528	490.9	122.5	214.5	122.74
	Ave	12.11	4609	405.0	121.9	210.5	118.17
	7.5	9.532	4188	459.6	112.2	195.6	111.49
COND	2.5	8.437	4206	503.3	115.5	204.9	115.18
	Ave	8.985	4197	481.5	113.9	200.2	113.34
	7.5	9.690	4179	450.8	112.0	194.9	110.77
CONDCV	2.5	8.750	4248	489.9	116.4	206.0	115.68
	Ave	9.220	4213	470.4	114.2	200.4	113.22
	7.5	14.53	4668	322.5	122.1	208.1	113.34
FCST	2.5	9.690	4631	494.2	124.8	218.2	125.68
	Ave	12.11	4649	408.4	123.4	213.2	119.51

TABLE XXI (Continued)

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	9.532	4169	457.2	111.8	194.8	110.90
COMFCST	2.5	8.282	4204	513.3	115.5	204.7	115.53
	Ave	8.907	4187	485.3	113.7	199.7	113.21
	7.5	9.377	4161	464.4	111.7	194.7	111.04
CONDFCST	2.5	8.437	4171	498.8	114.7	203.7	114.02
	Ave	8.907	4166	481.6	113.2	199.2	112.53
	7.5	9.845	4230	451.1	113.2	196.5	112.03
COMFCV	2.5	8.595	4272	500.1	117.1	206.8	116.89
	Ave	9.220	4251	475.6	115.2	201.7	114.46
	7.5	9.690	4179	450.8	112.0	194.9	110.77
CONDFCV	2.5	8.595	4231	496.5	116.1	205.6	115.56
	Ave	9.142	4205	473.6	114.0	200.2	113.16
	7.5	14.84	4694	315.8	121.6	207.2	113.35
PERFECT	2.5	10.93	4739	436.2	126.7	220.5	125.76
	Ave	12.89	4717	376.0	124.2	213.9	119.56

TABLE XXII

AVERAGE RESULTS OF 1984 THROUGH 1987 CROP GROWTH SIMULATION TRIALS FOR LOW IRRIGATION COST/HIGH CROP VALUE RATIO FOR LAST PLANT IRRIGATION SCENARIO

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	24.22	5942	247.5	140.4	225.3	716.52
GS0	2.5	22.81	5946	263.3	140.7	225.9	721.06
	Ave	23.52	5944	255.4	140.6	225.6	718.79
	7.5	24.22	5940	247.4	140.5	225.4	716.24
GS1	2.5	22.81	5953	263.7	141.0	226.3	721.94
	Ave	23.52	5946	255.6	140.7	225.9	719.09
	7.5	24.22	5843	243.2	138.6	222.4	703.48
GS3	2.5	22.03	5808	267.5	138.7	223.4	705.03
	Ave	23.13	5826	255.3	138.6	222.9	704.25
	7.5	24.22	5843	243.2	138.7	222.5	703.41
GS13	2.5	21.25	5844	279.4	139.5	225.0	711.90
	Ave	22.74	5843	261.3	139.1	223.8	707.65
	7.5	22.81	5825	257.6	139.7	226.0	705.04
DAILY	2.5	17.66	5635	324.8	138.8	228.1	694.43
	Ave	20.24	5730	291.2	139.2	227.0	699.74
	7.5	22.81	5855	259.0	139.8	225.4	709.01
DAILYCV	2.5	18.28	5702	315.8	139.5	228.6	701.42
	Ave	20.55	5778	287.4	139.7	227.0	705.21
	7.5	22.81	5810	256.8	139.5	225.7	703.00
COND	2.5	18.44	5693	312.7	139.7	229.3	699.76
	Ave	20.61	5751	284.8	139.6	227.5	701.39
	7.5	22.81	5838	258.1	139.5	224.9	706.77
CONDCV	2.5	18.44	5718	314.0	140.1	229.6	703.14
	Ave	20.63	5778	286.1	139.8	227.2	704.95
	7.5	22.81	5830	257.7	139.2	224.5	705.70
FCST	2.5	17.97	5686	320.7	139.6	228.7	700.17
	Ave	20.39	5758	289.2	139.4	226.6	702.93

TABLE XXII (Continued)

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	22.81	5791	255.9	138.8	224.6	700.59
COMFCST	2.5	17.35	5638	330.8	138.7	227.8	695.61
	Ave	20.08	5715	293.4	138.8	226.2	698.10
	7.5	22.81	5810	256.8	139.3	225.3	703.07
CONDFCST	2.5	17.03	5633	338.4	138.7	228.1	695.82
	Ave	19.92	5721	297.6	139.0	226.7	699.44
	7.5	22.81	5855	258.9	139.8	225.4	709.01
COMFCV	2.5	18.28	5716	316.5	139.6	228.5	703.34
	Ave	20.55	5786	287.7	139.7	226.9	706.17
	7.5	22.81	5474	258.9	139.8	225.4	709.01
CONDFCV	2.5	18.28	5701	315.8	139.5	228.6	701.38
	Ave	20.55	5778	287.4	139.7	227.0	705.19
	7.5	22.81	5838	258.3	139.5	225.0	706.76
PERFECT	2.5	18.28	5688	315.2	139.1	227.8	699.66
	Ave	20.55	5763	286.8	139.3	226.4	703.21

TABLE XXIII

AVERAGE RESULTS OF 1984 THROUGH 1987 CROP GROWTH SIMULATION TRIALS FOR TYPICAL IRRIGATION COST/CROP VALUE RATIO FOR LAST PLANT IRRIGATION SCENARIO

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	24.22	5942	247.5	140.4	225.3	324.35
GS0	2.5	22.81	5946	263.3	140.7	225.9	328.59
	Ave	23.52	5944	255.4	140.6	225.6	326.47
	7.5	24.22	5940	247.4	140.5	225.4	324.21
GS1	2.5	22.81	5953	263.7	141.0	226.3	329.02
	Ave	23.52	5946	255.5	140.7	225.9	326.61
	7.5	24.22	5843	243.2	138.6	222.4	317.83
GS3	2.5	22.03	5808	267.5	138.7	223.4	321.67
	Ave	23.13	5825	255.3	138.6	222.9	319.75
	7.5	24.22	5842	243.2	138.7	222.5	317.80
GS13	2.5	21.25	5844	279.4	139.5	225.0	326.19
	Ave	22.74	5843	261.3	139.1	223.8	322.00
	7.5	16.10	5019	312.1	127.8	215.4	286.16
DAILY	2.5	13.28	5098	384.9	133.9	229.7	299.27
	Ave	14.69	5058	348.5	130.9	222.6	292.71
	7.5	20.47	5579	280.1	136.1	222.8	310.93
DAILYCV	2.5	14.85	5358	363.4	136.6	229.6	312.05
	Ave	17.66	5469	321.8	136.4	226.2	311.49
	7.5	18.13	5078	283.9	127.6	213.6	284.42
COND	2.5	14.06	5237	377.0	135.5	229.7	306.27
	Ave	16.10	5157	330.5	131.6	221.7	295.35
	7.5	20.47	5586	274.2	136.9	224.4	311.40
CONDCV	2.5	14.85	5369	364.3	137.1	230.6	312.82
	Ave	17.66	5478	319.3	137.0	227.5	312.11
	7.5	20.47	5596	280.6	136.4	223.2	312.03
FCST	2.5	14.53	5348	371.7	136.5	229.5	312.30
	Ave	17.50	5472	326.2	136.5	226.4	312.17

TABLE XXIII (Continued)

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	16.10	5069	315.0	128.5	213.6	289.51
COMFCST	2.5	13.44	5233	391.2	135.6	224.7	307.78
	Ave	14.77	5151	353.1	132.0	219.1	298.64
	7.5	16.10	5019	312.1	127.8	215.4	286.16
CONDFCST	2.5	12.82	5090	402.3	133.8	229.6	300.03
	Ave	14.46	5054	357.2	130.8	222.5	293.10
	7.5	20.94	5598	272.2	136.3	222.7	310.87
COMFCV	2.5	14.38	5357	377.8	136.1	219.1	313.29
	Ave	17.66	5477	325.0	136.2	220.9	312.08
	7.5	20.47	5579	280.1	136.1	222.5	310.93
CONDFCV	2.5	14.85	5346	362.5	136.3	228.9	311.24
	Ave	17.66	5462	321.3	136.2	225.7	311.08
	7.5	21.10	5611	270.3	136.2	222.7	311.28
PERFECT	2.5	15.63	5379	350.1	136.2	227.7	311.26
	Ave	18.36	5495	310.2	136.2	225.2	311.27

TABLE XXIV

AVERAGE RESULTS OF 1984 THROUGH 1987 CROP GROWTH SIMULATION TRIALS FOR HIGH IRRIGATION COST/LOW CROP VALUE RATIO FOR LAST PLANT IRRIGATION SCENARIO

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	24.22	5942	247.5	140.4	225.3	128.27
GS0	2.5	22.81	5946	263.3	140.7	225.9	132.36
	Ave	23.52	5944	255.4	140.6	225.6	130.31
	7.5	24.22	5940	247.4	140.5	225.4	128.20
GS1	2.5	22.81	5953	263.7	140.9	226.3	132.57
	Ave	23.52	5946	255.5	140.7	225.9	130.38
	7.5	24.22	5843	243.2	138.6	222.4	125.01
GS3	2.5	22.03	5808	267.5	138.7	223.4	129.99
	Ave	23.13	5825	255.3	138.6	222.9	127.50
	7.5	24.22	5842	243.2	138.7	222.5	124.99
GS13	2.5	21.25	5844	279.4	139.5	225.0	133.34
	Ave	22.74	5843	261.3	139.1	223.8	129.17
	7.5	13.44	4346	324.2	114.9	198.5	105.79
DAILY	2.5	19.69	4365	467.0	119.0	209.7	116.94
	Ave	11.57	4355	395.6	116.9	204.1	111.36
	7.5	15.47	4794	309.4	123.6	209.6	114.89
DAILYCV	2.5	11.10	4754	431.3	127.0	220.9	125.82
	Ave	13.28	4774	370.3	125.3	215.2	120.35
	7.5	12.66	4336	354.4	114.7	198.3	107.65
COND	2.5	10.31	4487	447.9	121.5	213.5	119.22
	Ave	11.49	4412	401.2	118.1	205.9	113.44
	7.5	15.63	4834	30.5	122.4	216.2	115.77
CONDCV	2.5	11.72	4915	429.2	130.0	224.5	129.37
	Ave	13.67	4874	368.9	127.2	220.3	122.57
	7.5	15.32	4698	305.7	122.1	207.6	112.17
FCST	2.5	11.41	4771	434.7	127.7	220.9	125.50
	Ave	13.36	4734	370.2	124.9	214.3	118.84

TABLE XXIV (Continued)

Irrigation Scheduling Method	Net Irr.	Total Irr. App.	Yield	Irr. WUE	ET WUE	EP WUE	Return
	cm	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
	7.5	14.38	4486	312.0	117.8	202.1	107.78
COMFCST	2.5	10.47	4544	445.0	122.6	215.3	120.64
	Ave	12.43	4515	378.5	120.2	208.7	114.21
	7.5	13.44	4346	324.2	114.9	198.5	105.79
CONDFCST	2.5	19.69	4365	467.0	119.0	209.7	116.94
	Ave	11.57	4356	395.6	116.9	204.1	111.36
	7.5	15.50	4812	309.9	123.9	210.0	115.40
COMFCV	2.5	11.88	4848	416.7	128.9	223.0	126.74
	Ave	13.69	4830	363.3	126.4	216.5	121.07
	7.5	15.47	4794	309.4	123.6	209.6	114.89
CONDFCV	2.5	11.10	4754	431.3	127.0	220.9	125.82
	Ave	13.28	4774	370.3	125.3	215.2	120.35
	7.5	15.16	4796	315.3	123.6	210.0	115.81
PERFECT	2.5	11.88	4815	414.6	128.2	222.1	125.65
	Ave	13.52	4805	365.0	125.9	216.0	120.73

However, in this instance, return is simply the income generated by the value of the crop yield minus the single operating cost of irrigation pumping energy.

Middle Plant Versus Last Plant Comparison

It has been previously noted that a difference in yield occurs between the first watered and last watered plants in the field. Two methods of projecting the soil water level to account for the irrigation time interval were described and referred to as the middle plant and last plant methods. Returns for these two simulations were compared and the results are shown in Tables XXV through XXVII for each of the three levels of C/L ratio. Stage of growth irrigation schedules were not included in this comparison since the middle and last plant soil water projections were not used.

The mean return for all last plant irrigation scheduling methods was greater than the mean return for all middle plant methods. Only in the high irrigation cost/low crop value comparison were any of the individual returns higher for the middle plant method. Significant differences in return means (5% confidence level) were noted for the low irrigation cost/high crop value and the typical irrigation cost/crop value ratios. The return means of the high irrigation cost/low crop value were not significantly different at the 5% confidence level, although the tendency was for returns to be greater for the last plant method. Because of the general superiority of the last plant method,

TABLE XXV

COMPARISON OF RETURNS FOR MIDDLE PLANT AND LAST PLANT IRRIGATION SCENARIOS FROM A GRAIN SORGHUM SIMULATION TRIAL FOR THE LOW IRRIGATION COST/HIGH CROP VALUE RATIO

Irrigation Scheduling Method	Middle Plant Irrigation Scenario Return	Last Plant Irrigation Scenario Return
	$/ha	$/ha
DAILY	685.48	699.73
DAILYCV	688.83	705.21
COND	659.86	701.39
CONDCV	665.95	704.95
FCST	683.53	702.93
COMFCST	656.99	698.10
CONDFCST	656.01	699.44
COMFCV	672.02	706.17
CONDFCV	669.34	705.19
PERFECT	692.03	703.21
MEAN	673.00	702.63

TABLE XXVI

COMPARISON OF RETURNS FOR MIDDLE PLANT AND LAST PLANT IRRIGATION SCENARIOS FROM A GRAIN SORGHUM SIMULATION TRIAL FOR THE TYPICAL IRRIGATION COST/CROP VALUE RATIO

Irrigation Scheduling Method	Middle Plant Irrigation Scenario Return	Last Plant Irrigation Scenario Return
	$/ha	$/ha
DAILY	290.93	292.71
DAILYCV	307.11	311.49
COND	278.87	295.35
CONDCV	281.31	312.11
FCST	304.92	312.17
COMFCST	279.00	298.64
CONDFCST	278.57	293.10
COMFCV	281.28	312.08
CONDFCV	281.31	311.08
PERFECT	308.89	311.27
MEAN	289.22	305.27

TABLE XXVII

COMPARISON OF RETURNS FOR MIDDLE PLANT AND LAST PLANT IRRIGATION SCENARIOS FROM A GRAIN SORGHUM SIMULATION TRIAL FOR THE HIGH IRRIGATION COST/LOW CROP VALUE RATIO

Irrigation Scheduling Method	Middle Plant Irrigation Scenario Return	Last Plant Irrigation Scenario Return
	$/ha	$/ha
DAILY	115.27	111.36
DAILYCV	118.18	120.35
COND	113.34	113.44
CONDCV	113.23	122.57
FCST	119.52	118.84
COMFCST	113.22	114.21
CONDFCST	112.54	111.36
COMFCV	114.47	121.07
CONDFCV	113.17	120.35
PERFECT	119.56	120.73
MEAN	115.25	117.43

all additional analysis will be based on this method.

Last Plant Analysis

The grain sorghum model, SORGF, is a deterministic model, so only single data points for yield can be generated for each year for a given set of starting parameters and rainfall probability estimates. Yields are estimated by averaging yield from first watered and last watered plants in the field. Both growth stage and C/L scheduling methods used this average yield estimate, although growth stage scheduling methods did not use projected soil water values in determining the irrigation schedule. To aid the statistical analysis of the information, the four years were paired based on rainfall amounts. 1984 and 1985 were relatively dry years, with rainfall amounts of 9.40 cm and 16.84 cm, respectively. 1986 and 1987 were relatively wet years with rainfall amounts of 20.60 cm and 26.27 cm, respectively. This pairing allows an estimate of the effect of "years" to be made.

Economic return to the irrigator was used to identify the last plant soil water projection method as the superior method of the two described. Return is an important criterion for determining the benefits of a particular methodology. Total irrigation application is also an important production consideration, especially in light of the declining water resource base. Information on yield, water use efficiency (WUE), evapotranspiration (ET), and plant transpiration (EP) may also be useful. The following analysis will concentrate on return and total irrigation applied, although general trends of the other crop production parameters are noted and are discussed in a later section.

<u>Results Common to All C/L Ratios</u>

An analysis of variance test was performed on return and total irrigation application data, with the division between years included as part of the analysis. Net application per irrigation, method of irrigation scheduling, and all interactions were included in the statistical model. All tests for statistically significant differences were performed using a 5% confidence level. Summaries from the complete statistical model of statistical differences for return and total irrigation application are shown in Tables XXVIII through XXX for each C/L ratio.

The complete statistical model indicated that a difference in returns between the paired years is apparent at each level of C/L ratio. Differences due to yearly effects is not unexpected. However, in this instance, dry years had greater average return than wet years. This indicates that rainfall is not the only production factor involved. Irrigated crop production should tend to diminish the effect of rainfall differences between years, but many other production factors, such as plant population, temperatures, and rainfall distribution, play a role. An

TABLE XXVIII

SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES
FOR RETURN AND TOTAL IRRIGATION APPLICATION
FOR A GRAIN SORGHUM SIMULATION TRIAL
USING A LOW IRRIGATION COST/HIGH
CROP VALUE RATIO

Significant Factor	Return $/ha	Significant Factor	Irrigation cm
Year:		Year:	
Dry	745.94	Dry	22.26
Wet	664.94	Wet	20.17
		Net Irr:	
		7.5	23.22
		2.5	19.21

TABLE XXIX

SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES FOR RETURN AND TOTAL IRRIGATION APPLICATION FOR A GRAIN SORGHUM SIMULATION TRIAL USING A TYPICAL IRRIGATION COST/CROP VALUE RATIO

Significant Factor	Return $/ha	Significant Factor			Irrigation cm
Year:		Year:			
Dry	327.62	Dry			19.92
Wet	293.07	Wet			17.13
		Net Irr:			
		7.5			20.52
		2.5			16.54
		Method:			
		GS0		A*	23.52
		GS1		A	23.52
		GS3		A	23.13
		GS13		A	22.74
		PERFECT	C	B	18.36
		CONDFCV	C	B	17.66
		CONDCV	C	B	17.66
		DAILYCV	C	B	17.66
		COMFCV	C	B	17.66
		FCST	C	B	17.50
		COND	C	B	16.10
		COMFCST	C	B	14.77
		DAILY	C	B	14.69
		CONDFCST	C		14.46

*Means with the same letter are not significantly different at the 5% confidence level.

TABLE XXX

SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES FOR RETURN AND TOTAL IRRIGATION APPLICATION FOR A GRAIN SORGHUM SIMULATION TRIAL USING A HIGH IRRIGATION COST/LOW CROP VALUE RATIO

Significant Factor	Return $/ha	Significant Factor		Irrigation cm
Year:		Year:		
Dry	127.98	Dry		17.08
Wet	113.68	Wet		14.46
Net Irr:		Net Irr:		
7.5	115.89	7.5		17.38
2.5	125.78	2.5		14.15
		Method:		
		GS0	A*	23.52
		GS1	A	23.52
		GS3	A	23.13
		GS13	A	22.74
		COMFCV	B	13.69
		CONDFCV	B	13.67
		PERFECT	B	13.52
		FCST	B	13.36
		CONDFCV	B	13.28
		DAILYCV	B	13.28
		COMFCST	B	12.43
		CONDFCST	B	11.57
		DAILY	B	11.57
		COND	B	11.49

*Means with the same letter are not significantly different at the 5% confidence level.

important difference between years is the planting date, particularly for 1986 when a late planting date occurred. 1986 had the lowest yield levels of all years, (see Tables XLV through LXXIV, Appendix C). The large difference between wet year yield levels causes higher standard deviations than in dry years, which makes detection of statistically significant differences more difficult.

Total irrigation application was also dependent on years. As logically expected, dry years had higher total irrigation applications than wet years.

In the strict statistical sense, further observations concerning the effect of net irrigation application and method of scheduling on return are clouded by the differences due to the pairing of the years. However, the irrigation scheduling procedure is not inherently dependent on whether the year is wet or dry because the decision to irrigate is made on a daily basis. Therefore, all significant differences are noted in Tables XXVIII through XXX. Analysis of return and total irrigation application for within year comparisons for each C/L ratio are discussed in later sections.

Net irrigation application caused statistically significant differences in return only in the high irrigation cost/low crop value ratio, with the 2.5 cm net application having the higher mean return. The 7.5 cm net application applied significantly more irrigation water than the 2.5 cm net application for all three C/L ratios. The model, which would adjust the last irrigation application to coincide with crop physiological maturity, could not interrupt an irrigation once initiated. This means the 7.5 cm net application has fewer decision points within a growing season after irrigation begins. Consequently, there is less opportunity to take advantage of large rainfall events that may occur during an irrigation interval. The smaller net irrigation application will be able to incorporate the event into its decision-making process earlier. The smaller net application also provides more opportunities to make incorrect decisions (i.e., failing to initiate an irrigation). However incorrect decisions for one day result in only minimal damage if a correct decision is made the following day.

No significant differences in return were noted due to scheduling method for any of the C/L ratios. The perfect forecast did not distinguish itself from the other forecast methods. The perfect forecast always made correct decisions by delaying irrigation on days with rainfall, however the relatively high frequency of very small rainfall events made many of the delay decisions essentially incorrect. Small rainfall events do not restore soil water depletions sufficiently to prevent yield limitations. The probabilistic forecast and forecasts associated with a critical rainfall amount tended to have returns as good or better than the perfect forecast.

There were significant differences in total irrigation application for the typical C/L ratio and the high irrigation cost/low crop value ratio. The stage of growth scheduling methods applied significantly more water than did the C/L methods.

Low Irrigation Cost/High Crop Value Analysis

The average results for both levels of net irrigation application and all years are shown in Figures 16 and 17 for return, total irrigation application, yield, irrigation WUE, ET WUE, EP WUE, ET, and EP, for each method of scheduling. The arrangement of irrigation scheduling methods on the horizontal axis is in decreasing order of return. All other crop production parameters are presented in this order and follow this descending trend except for irrigation WUE, which is ascending, and EP WUE, which has no clear trend.

Average return and total irrigation application for each scheduling method are shown in Table XXXI. GS1 and GS0 have the highest returns. All other scheduling methods result in similar values. The growth stage scheduling methods, as a group, apply similar amounts of water that appear to be at a higher level than C/L methods.

An analysis of variance test was performed on return and total irrigation application data, with the division between years included as part of the analysis (the results of which were presented previously). Since a statistically significant difference in return was noted due to years, an additional analysis of variance was performed on each set of

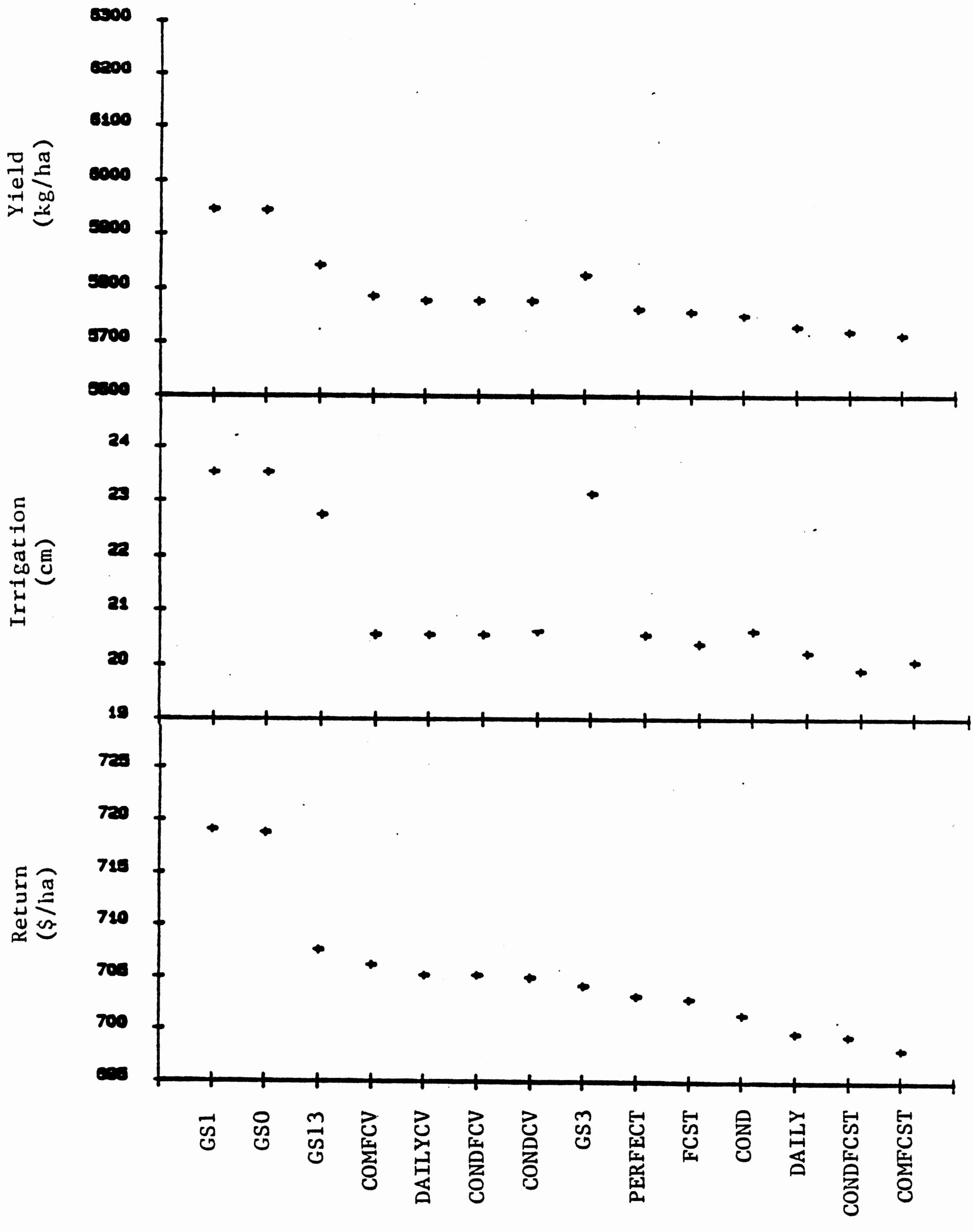

Figure 16. RETURN, IRRIGATION, AND YIELD VERSUS IRRIGATION SCHEDULING METHOD FOR A GRAIN SORGHUM SIMULATION TRIAL USING A LOW IRRIGATION COST/HIGH CROP VALUE RATIO

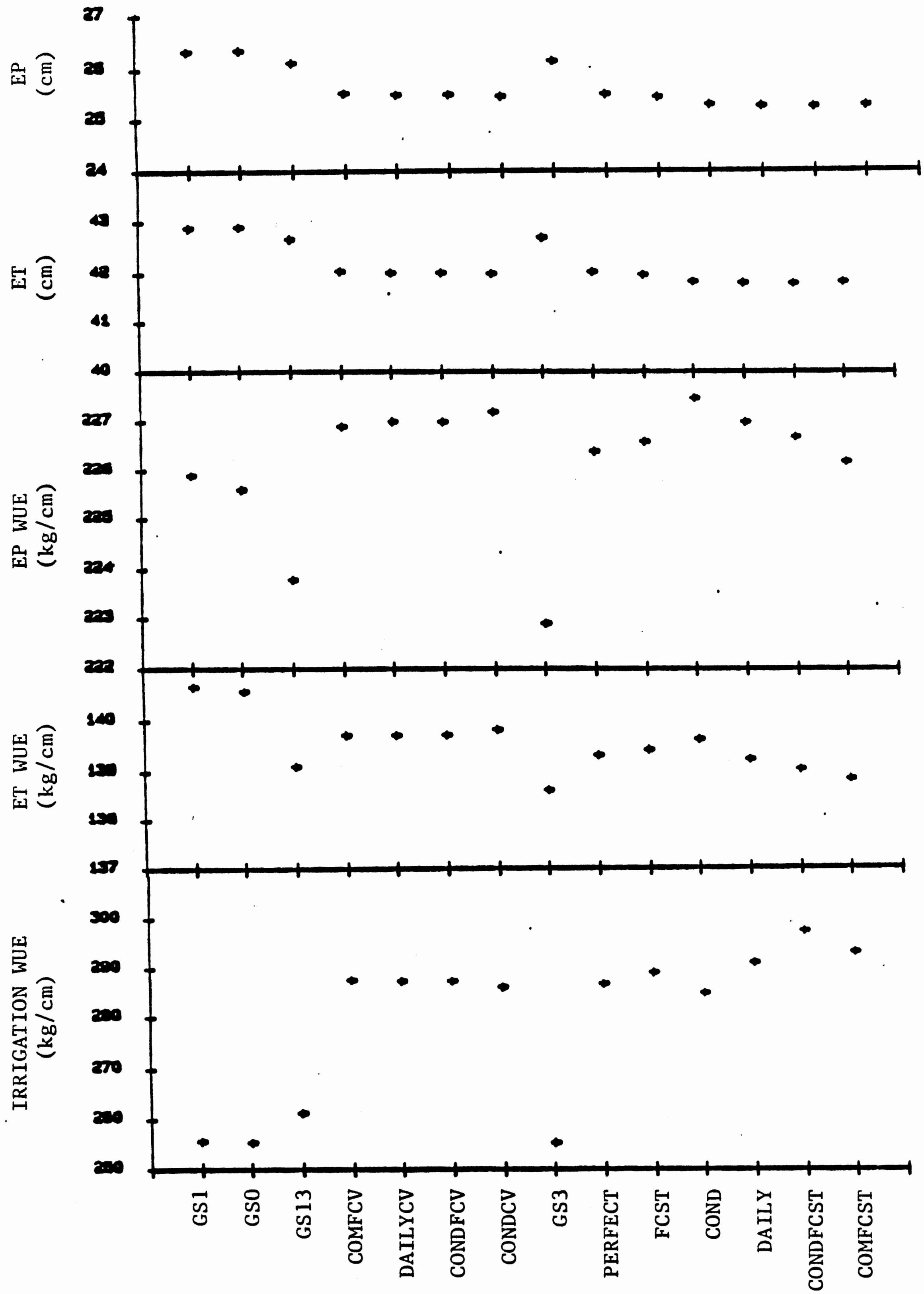

Figure 17. IRRIGATION WUE, ET WUE, EP WUE, ET, AND EP VERSUS IRRIGATION SCHEDULING METHOD FOR A GRAIN SORGHUM SIMULATION USING A LOW IRRIGATION COST/HIGH CROP VALUE RATIO

TABLE XXXI

AVERAGE RETURN AND TOTAL IRRIGATION APPLICATION FROM A GRAIN SORGHUM SIMULATION TRIAL USING A LOW IRRIGATION COST/HIGH CROP VALUE RATIO

Method of Scheduling	Return $/ha	Method of Scheduling	Irrigation cm
GS1	719.09	CONDFCST	19.92
GS0	718.79	COMFCST	20.08
GS13	707.65	DAILY	20.24
COMFCV	706.17	FCST	20.39
DAILYCV	705.21	COMFCV	20.55
CONDFCV	705.19	PERFECT	20.55
CONDCV	704.95	DAILYCV	20.55
GS3	704.25	CONDFCV	20.55
PERFECT	703.21	CONDCV	20.63
FCST	702.93	COND	20.63
COND	701.39	GS13	22.74
DAILY	699.73	GS3	23.13
CONDFCST	699.44	GS1	23.52
COMFCST	698.10	GS0	23.52

data from the wet and dry years. The summary of all significant effects is shown in Table XXXII.

This analysis indicated no statistically significant difference in return based on either net irrigation application or scheduling method during the wet years.

The return from dry years was found to be dependent on both net irrigation application and method of scheduling. The return for the 7.5 cm net irrigation application (mean $748.40/ha) was significantly greater than the return for the 2.5 cm net irrigation application (mean $743.47/ha). Duncan's Multiple Range Test was used to compare returns from the various methods of irrigation scheduling. The returns based on scheduling by stage of growth are significantly greater than returns from other methods.

An analysis of variance test showed significant differences for total irrigation applied in wet years due to net application, scheduling method and their interaction. The interaction of method and net application indicates that one must be specified in order to make confident statements concerning the other. For every instance in 1986 and 1987, a total of 22.50 cm of irrigation was applied for the 7.5 cm net application. The 2.5 cm net application had total irrigation application amounts ranging from 15.00 cm to 21.88 cm (mean 17.84 cm). The 7.5 cm net application had more total irrigation water applied for every scheduling method than the 2.5 cm net application, although GS0 and GS1 methods were close. The method of scheduling made no

TABLE XXXII

SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES FOR RETURN AND TOTAL IRRIGATION APPLICATION FOR A GRAIN SORGHUM SIMULATION TRIAL USING A LOW IRRIGATION COST/HIGH CROP VALUE RATIO FOR WITHIN YEAR COMPARISONS

Wet Years		Wet Years		
Significant Factor	Return $/ha	Significant Factor		Irrigation cm
None		Net Application		
		7.5		22.50
		2.5		17.84
		Scheduling Method		
		GS0	A*	22.19
		GS1	A	22.19
		GS3	AB	21.41
		GS13	CB	20.63
		COND	CD	20.00
		CONDCV	CD	20.00
		CONDFCV	CD E	19.85
		DAILYCV	CD E	19.85
		PERFECT	CD E	19.85
		COMFCV	CD E	19.85
		FCST	FD E	19.53
		DAILY	FD E	19.38
		COMFCST	F E	18.91
		CONDFCST	F	18.75
		NET X METH		
		2.5 NET		
		GS0	A*	21.88
		GS1	A	21.88
		GS3	AB	20.32
		GS13	CB	18.76
		COND	CD	17.50
		CONDCV	CD	17.50

TABLE XXXII (Continued)

Significant Factor		Return $/ha	Significant Factor		Irrigation cm
Wet Years			Wet Years		
			2.5 NET (continued)		
			CONDFCV	CD E	17.19
			DAILYCV	CD E	17.19
			PERFECT	CD E	17.19
			COMFCV	CD E	17.19
			FCST	FD E	16.57
			DAILY	FD E	16.25
			COMFCST	F E	15.32
			CONDFCST	F	15.00
			7.5 Net		
			ALL METHOD MEANS		22.50
Dry Years			Dry Years		
Net Application			Net Application		
7.5		748.40	7.5		23.93
2.5		743.47	2.5		20.58
Scheduling Method					
GS1	A*	759.90			
GS0	A	759.21			
GS13	A	757.58			
GS3	A	757.08			
COMFCV	B	744.41			
CONDCV	B	743.39			
DAILYCV	B	742.80			
CONDCV	B	742.77			
COND	B	741.09			
FCST	B	740.32			
DAILY	B	740.10			
PERFECT	B	738.58			
CONDFCST	B	738.27			
COMFCST	B	737.63			

*Means with the same letter are not significantly different at the 5% confidence level.

difference for the 7.5 net application but did have an effect on total irrigation application for the 2.5 cm net application.

Typical Irrigation Cost/Crop Value Analysis

The average results for both levels of net irrigation application and all years are shown in Figures 18 and 19. The arrangement of the irrigation scheduling method on the horizontal axis is in decreasing order of return. All other production parameters are presented in this order and follow this descending trend except for irrigation WUE, which is ascending, and EP WUE, which has no clear trend.

Average return and total irrigation application for each scheduling method are shown in Table XXXIII. The stage of growth methods have the highest level of return. FCST, PERFECT, and the methods associated with a critical rainfall value appear to form a second group. All stage of growth methods apply a high level of irrigation water compared to C/L methods. A difference in the total irrigation applied also appears to exist within the C/L methods. Those with the lowest return also tend to apply the least amount of irrigation water.

An analysis of variance test was performed on return and total irrigation application data, with the division between years included as part of the analysis (the results of which were presented previously). These results indicated significant differences in return and total

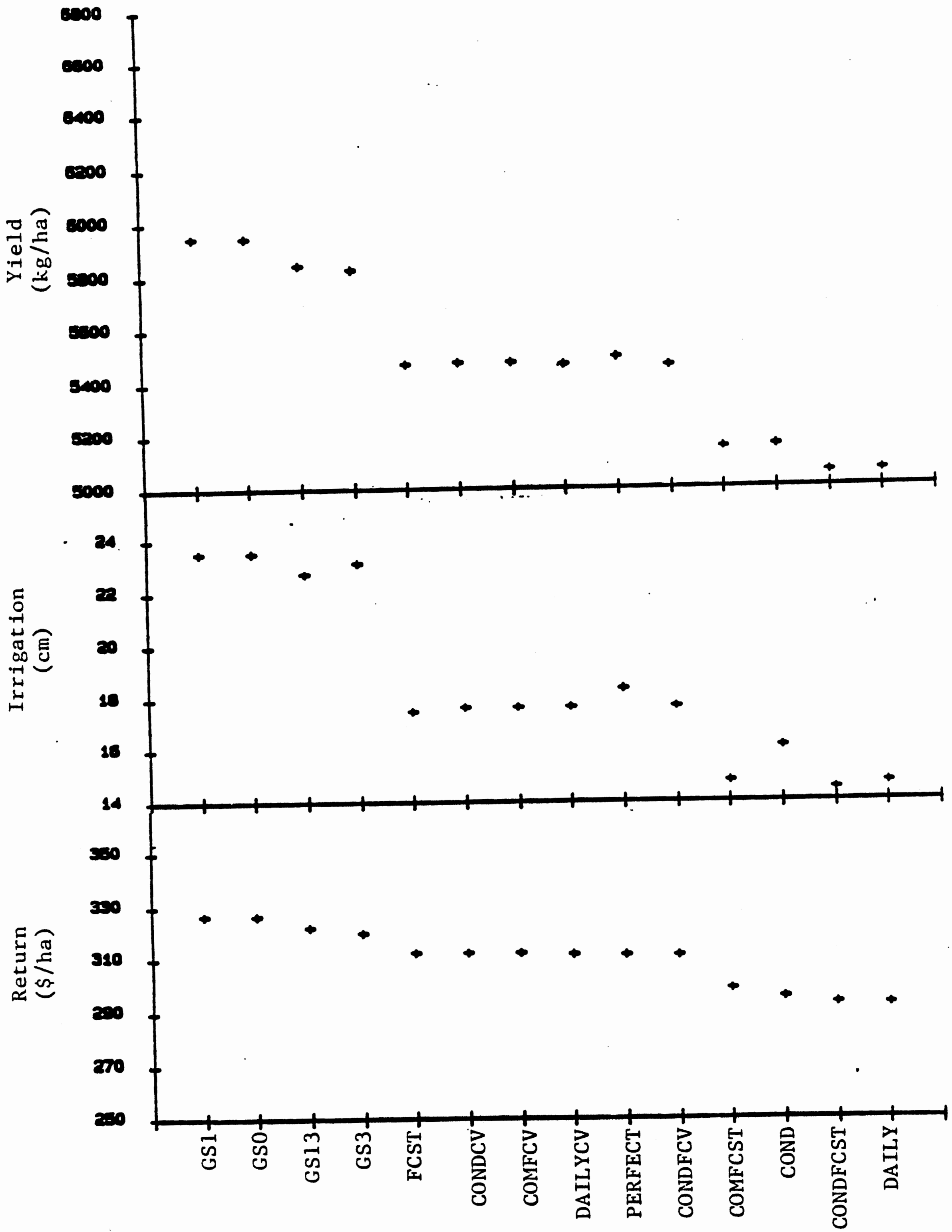

Figure 18. RETURN, IRRIGATION, AND YIELD VERSUS IRRIGATION SCHEDULING METHOD FOR A GRAIN SORGHUM SIMULATION TRIAL USING A TYPICAL IRRIGATION COST/HIGH CROP VALUE RATIO

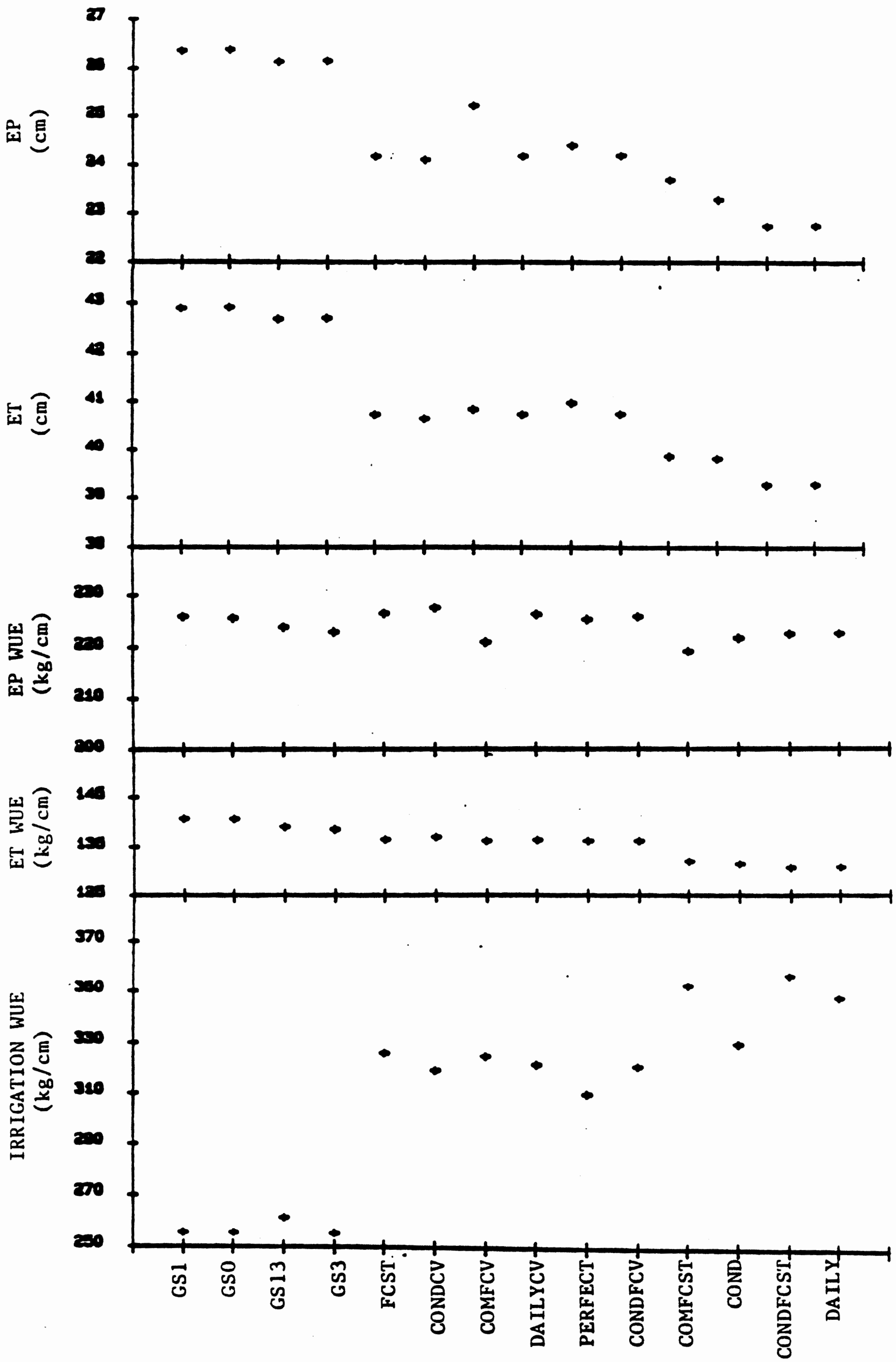

Figure 19. IRRIGATION WUE, ET WUE, EP WUE, ET, AND EP VERSUS IRRIGATION SCHEDULING METHOD FOR A GRAIN SORGHUM SIMULATION USING A TYPICAL IRRIGATION COST/CROP VALUE RATIO

TABLE XXXIII

AVERAGE RETURN AND TOTAL IRRIGATION APPLICATION FROM A GRAIN SORGHUM SIMULATION TRIAL USING A TYPICAL COST/CROP VALUE RATIO

Method of Scheduling	Return $/ha	Method of Scheduling	Irrigation cm
GS1	326.61	CONDFCST	14.46
GS0	326.47	DAILY	14.69
GS13	322.00	COMFCST	14.77
GS3	319.75	COND	16.10
FCST	312.17	FCST	17.50
CONDCV	312.11	COMFCV	17.66
COMFCV	312.08	DAILYCV	17.66
DAILYCV	311.49	CONDCV	17.66
PERFECT	311.27	CONDFCV	17.66
CONDFCV	311.08	PERFECT	18.36
COMFCST	298.64	GS13	22.74
COND	295.35	GS3	23.13
CONDFCST	293.10	GS1	23.52
DAILY	292.71	GS0	23.52

irrigation application due to years. A summary of all significant effects for within year comparisons is shown in Table XXXIV.

Both the dry year and wet year analysis of variance indicated no statistically significant differences in returns based on either net irrigation application or scheduling method.

The wet year analysis of variance indicated statistically significant differences in total irrigation applications due to net irrigation application and method of scheduling. The 7.5 cm net application applied an average of 19.15 cm compared to 15.11 cm for the 2.5 cm net application.

The method of scheduling comparisons were made using Duncan's Multiple Range Test. Three groups of scheduling methods were identified as applying similar amounts of water. Stage of growth application methods were in the highest total irrigation application group.

The dry year analysis of variance on total irrigation application also indicated statistically significant differences due to net irrigation application and method of scheduling. The 7.5 cm net application mean for total irrigation application was 21.88 cm compared to 17.97 cm for the 2.5 cm net application.

Duncan's Multiple Range Test identified two groups of scheduling methods with some overlapping of groups. However, the stage of growth methods applied the greatest amount of

TABLE XXXIV

SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES FOR RETURN AND TOTAL IRRIGATION APPLICATION FOR A GRAIN SORGHUM SIMULATION TRIAL USING A TYPICAL IRRIGATION COST/CROP VALUE RATIO FOR WITHIN YEAR COMPARISONS

Wet Years		Wet Years		
Significant Factor	Return $/ha	Significant Factor		Irrigation cm
None		Net Application		
		7.5		19.15
		2.5		15.11
		Scheduling Method		
		GS0	A*	22.19
		GS1	A	22.19
		GS3	A	21.41
		GS13	A	20.63
		CONDCV	B	17.19
		PERFECT	B C	16.88
		CONDFCV	B C	16.25
		DAILYCV	B C	16.25
		COMFCV	B C	16.10
		FCST	B C	15.78
		COND	B C	14.53
		COMFCST	B C	13.75
		DAILY	B C	13.60
		CONDFCST	C	13.13

TABLE XXXIV (Continued)

Dry Years		Dry Years		
Significant Factor	Return $/ha	Significant Factor		Irrigation cm
None		Net Application		
		7.5		21.88
		2.5		17.97
		Scheduling Method		
		GS0	A*	24.85
		GS1	A	24.85
		GS3	A	24.85
		GS13	A	24.85
		PERFECT	AB	19.85
		FCST	AB	19.22
		COMFCV	AB	19.22
		CONDFCV	AB	19.07
		DAILYCV	AB	19.07
		CONDCV	B	18.13
		COND	B	17.66
		CONDFCST	B	15.78
		DAILY	B	15.78
		COMFCST	B	15.78

*Means with the same letter are not significantly different at the 5% confidence level.

irrigation water of those in the higher group.

High Irrigation Cost/Low Crop Value Analysis

The average results for both levels of net irrigation application and all years are shown in Figures 20 and 21. The arrangement of the irrigation scheduling methods on the horizontal axis is in order of decreasing return. All other parameters are presented in this order, and follow this descending trend except for irrigation WUE, which is ascending.

Average return and total irrigation application for each scheduling method are shown in Table XXXV. The stage of growth methods have the highest returns. Scheduling methods associated with a critical rainfall value, along with PERFECT, and possibly FCST appear as the next highest level of return. Stage of growth methods clearly apply more irrigation water than C/L methods.

An analysis of variance test was performed on return and total irrigation application data, with the division between years included as part of the analysis (the results of which were presented previously). These results had indicated significant differences in return and total irrigation application due to years. Analysis of variance tests were made for within year comparisons of return and total irrigation and all significant effects are summarized in Table XXXVI.

Statistical analysis of wet year returns indicated

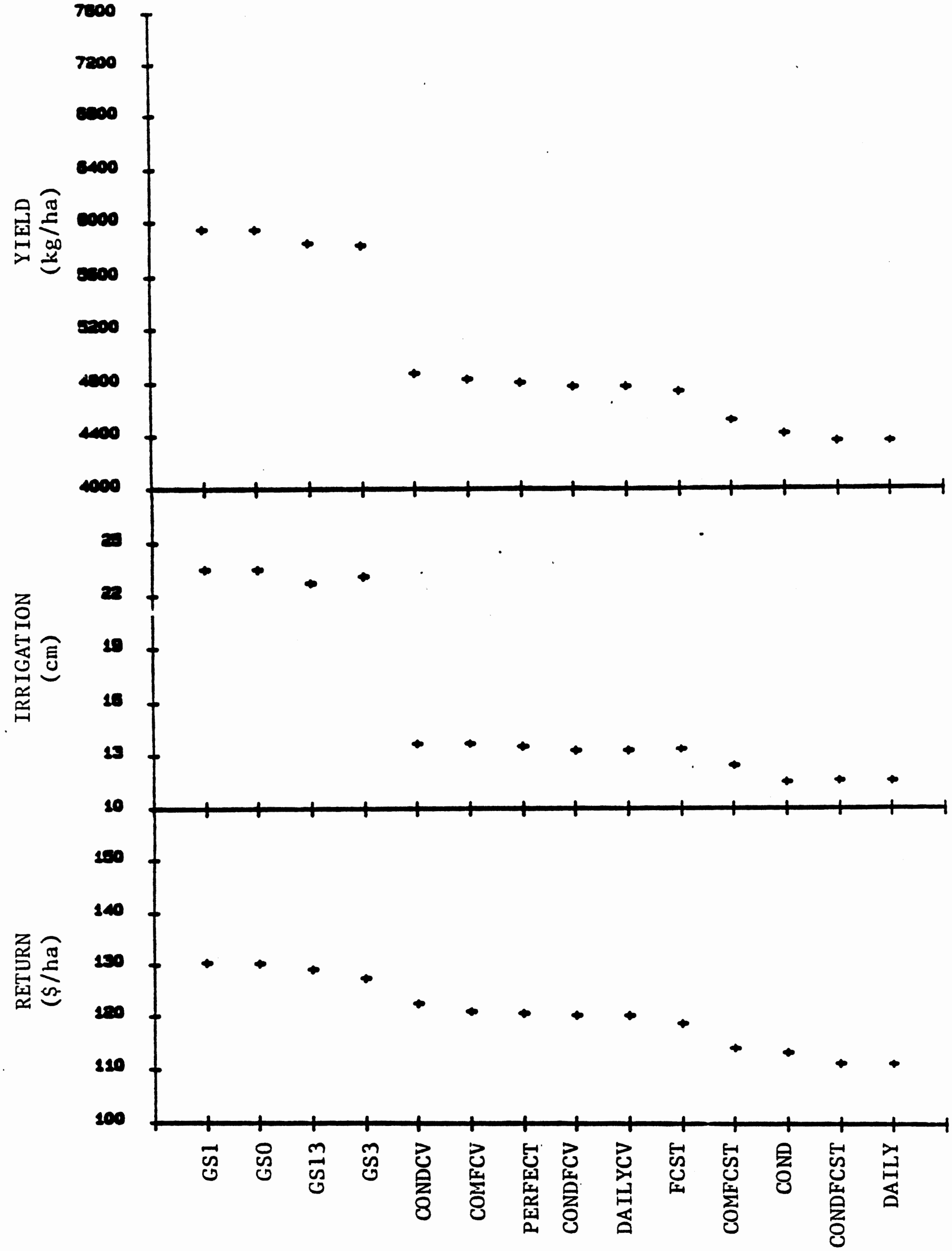

Figure 20. RETURN, IRRIGATION, AND YIELD VERSUS IRRIGATION SCHEDULING METHOD FOR A GRAIN SORGHUM SIMULATION TRIAL USING A HIGH IRRIGATION COST/LOW CROP VALUE RATIO

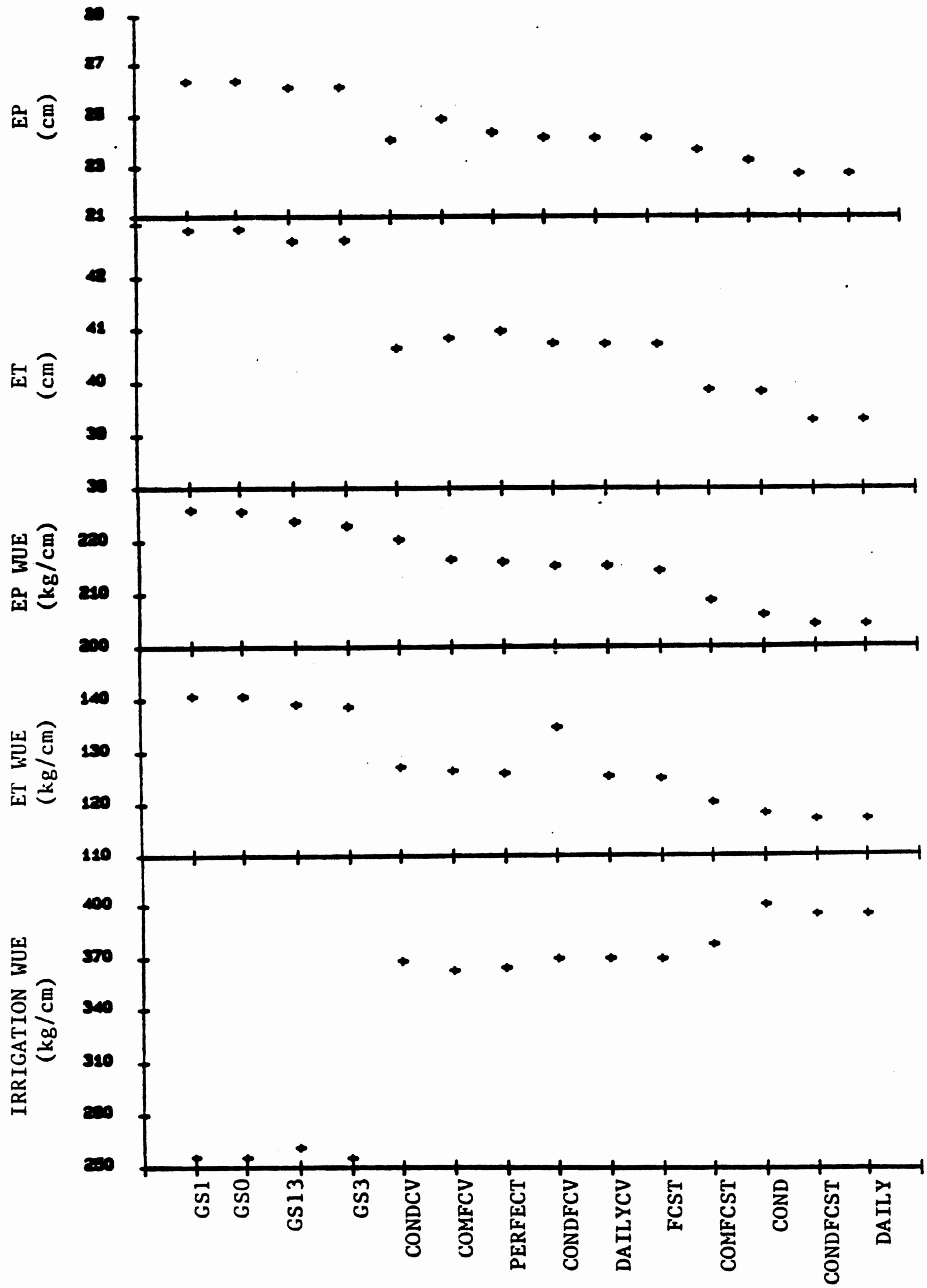

Figure 21. IRRIGATION WUE, ET WUE, EP WUE, ET, AND EP VERSUS IRRIGATION SCHEDULING METHOD FOR A GRAIN SORGHUM SIMULATION USING A HIGH IRRIGATION COST/LOW CROP VALUE RATIO

TABLE XXXV

AVERAGE RETURN AND TOTAL IRRIGATION APPLICATION FROM A GRAIN SORGHUM SIMULATION TRIAL USING A HIGH IRRIGATION COST/LOW CROP VALUE RATIO

Method of Scheduling	Return $/ha	Method of Scheduling	Irrigation cm
GS1	130.38	COND	11.49
GS0	130.31	DAILY	11.57
GS13	129.17	CONDFCST	11.57
GS3	127.50	COMFCST	12.43
CONDCV	122.57	DAILYCV	13.28
COMFCV	121.07	CONDFCV	13.28
PERFECT	120.73	FCST	13.36
CONDFCV	120.35	PERFECT	13.52
DAILYCV	120.35	CONDCV	13.67
FCST	118.84	COMFCV	13.69
COMFCST	114.21	GS13	22.74
COND	113.44	GS3	23.13
CONDFCST	111.36	GS1	23.52
DAILY	111.36	GS0	23.52

TABLE XXXVI

SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES FOR RETURN AND TOTAL IRRIGATION APPLICATION FOR A GRAIN SORGHUM SIMULATION TRIAL USING A HIGH IRRIGATION COST/LOW CROP VALUE RATIO FOR WITHIN YEAR COMPARISONS

Wet Years		Wet Years		
Significant Factor	Return $/ha	Significant Factor		Irrigation cm
Net Application		Net Application		
7.5	107.42	7.5		16.46
2.5	119.94	2.5		12.46
		Scheduling Method		
		GS0	A*	22.19
		GS1	A	22.19
		GS3	A	21.41
		GS13	A	20.63
		COMFCV	B	12.37
		CONDFCV	B	12.35
		DAILYCV	B	12.35
		PERFECT	B	12.35
		CONDCV	B	12.35
		FCST	B C	11.89
		COMFCST	B C	11.57
		CONDFCST	C	10.32
		DAILY	C	10.32
		COND	C	10.16

TABLE XXXVI (Continued)

Dry Years		Dry Years		
Significant Factor	Return $/ha	Significant Factor		Irrigation cm
None		Net Application		
		7.5		18.31
		2.5		15.85
		Scheduling Method		
		GS1	A*	24.85
		GS0	A	24.85
		GS13	A	24.85
		GS3	A	24.85
		CONDCV	B	15.00
		COMFCV	B	15.00
		FCST	B	14.85
		PERFECT	B	14.69
		CONDFCV	B	14.22
		DAILYCV	B	14.22
		COMFCST	B	13.29
		COND	B	12.82
		CONDFCST	B	12.82
		DAILY	B	12.82

*Means with the same letter are not significantly different at the 5% confidence level.

significant differences due to net irrigation application with 2.5 cm net application (mean $119.94/ha) being greater than 7.5 cm net application (mean $107.42/ha).

The wet year analysis also indicated total irrigation application is dependent on net application and method of scheduling. The 7.5 cm net application mean was 16.46 cm compared to 12.46 cm for the 2.5 cm net application. Stage of growth scheduling methods applied significantly more water than other methods.

Statistical analysis of returns for dry years resulted in no significant differences in returns due to either method of irrigation scheduling or net application amount.

The dry year analysis indicated that total irrigation application depended on net irrigation and method of scheduling. The 7.5 cm net application applied an average of 18.31 cm compared to 15.85 cm for the 2.5 cm net application. Duncan's Multiple Range Test indicated growth stage methods applied significantly more water than did other methods.

Trends of Production Parameters For All C/L Ratios

Return. Returns obviously reduce as crop price drops from high crop value to typical crop value to low crop value. The differences between scheduling methods with the highest and lowest return for each C/L ratio were $20.99/ha, $33.90/ha, and $19.02/ha, respectively. Returns for each ratio were statistically analyzed and shown previously.

Total Irrigation Application. Total irrigation application is the net total amount of irrigation water applied during a single growing season. Total irrigation application for the stage of growth irrigation scheduling methods remained constant for the three C/L ratios. Total irrigation application for the other scheduling methods decreased as irrigation cost/crop value ratios increased, i.e., as water became more valuable relative to crop value. This is an expected result of the risk analysis decision-making process. Total irrigation application data for each ratio were statistically analyzed and shown previously.

Yield. Yields for stage of growth scheduling methods remain constant for the three C/L ratios. As expected, yields for the remaining scheduling methods decrease as irrigation cost/crop value ratios increase, since crop value decreases relative to irrigation water cost.

Irrigation WUE. Irrigation WUE is the yield of the crop divided by the total net irrigation water applied. Irrigation WUE values for the stage of growth scheduling procedures remain constant for the three C/L ratios. Irrigation WUE increases with increasing C/L ratios for the other irrigation scheduling methods. The stage of growth scheduling methods maintain soil water at much higher levels than do the C/L scheduling methods, particularly for the typical irrigation cost/crop value ratio and high irrigation cost/low crop value ratio. Additional water at low soil water levels results in greater yield increases per unit of water than water added at high soil water levels (see Figure 10). Higher irrigation WUE does not necessarily translate into higher yield since total irrigation water applied may be restricted so much as to offset the gain in WUE.

ET WUE. ET WUE is the yield of the crop divided by the amount of ET. ET WUE for the stage of growth methods of scheduling remains constant for the three levels of C/L ratio. For the other scheduling methods, ET WUE values for the low irrigation cost/high crop value ratio were nearly identical to stage of growth ET WUE. ET WUE decreased with increasing irrigation cost or decreasing crop value. As a consequence of reducing irrigation applications it might have been hoped that reducing irrigation frequency would reduce soil evaporation and therefore reduce ET with minimal reductions in plant transpiration, EP. The downward trend in ET WUE with increasing C/L ratio indicates ET reductions due to decreased irrigation water were proportionally smaller than reductions in yield.

EP WUE. EP WUE is the yield of the crop divided by the plant transpiration. EP WUE for the stage of growth methods of scheduling remains constant for the three levels of C/L ratio. The other scheduling methods had declining EP WUE compared to the growth stage methods, particularly for the high irrigation cost/low crop value ratio. Declining EP WUE for increasing C/L ratios seems logical, since water restrictions to the crop occur that may become yield limiting. Irrigation WUE appears to be the most important of the WUE measures since it measures yield per unit of resource investment.

ET. ET remains constant for all stage of growth methods of scheduling for the three C/L ratios. ET values for other scheduling methods are less than stage of growth methods and are increasingly less for increasing C/L ratios. Decreasing ET would be a logical expectation for scheduling methods which reduce the frequency of irrigation events.

EP. EP remains constant for all stage of growth methods of scheduling for the three levels of C/L ratio. The other scheduling methods have declining EP with increasing C/L ratios. This would be the expected result since decreased total irrigation application may restrict soil water and therefore plant transpiration.

Effects of Increased Magnitude of Rainfall on Selected Scheduling Methods

An additional set of simulation trials was completed for GS0, GS1, GS3, GS13, FCSTM, and FCSTL scheduling methods in exactly the same manner as previous trials with the exception that all rainfall events were doubled in magnitude. While this does not precisely reflect a more humid climate, since rainfall frequency was not altered, it may help indicate if the C/L decision-making process has usefulness in other situations. M and L of FCSTM and FCSTL represent middle plant and last plant irrigation scenarios, while FCST refers to the probabilistic forecast.

Average return and total irrigation application for each method of scheduling and the three C/L ratios are shown in Table XXXVII. Data for individual years are shown in Tables LXIX through LXXIV in Appendix C. Returns are listed from the highest to lowest values, while total irrigation application is listed from lowest to highest. Returns for the low irrigation cost/high crop value ratio vary only slightly due to scheduling method, with FCSTM at a lower return level. FCSTM applies the least amount of irrigation water. FCSTL also applies less irrigation water than the stage of growth methods.

The range of average return narrows in the typical C/L ratio comparison. FCSTM and FCSTL continue to decrease total irrigation application.

In the final C/L ratio comparison, the FCST methods have the highest average returns, although the returns appear to be similar for all methods. This does represent the first time that a growth stage method did not have the highest return. FCST methods clearly apply less irrigation water than growth stage methods for this C/L ratio.

An analysis of variance test was performed on return and total irrigation application using the statistical model that was described previously. A summary of statistically significant differences for full model and within year comparisons is shown in Table XXXVIII.

The full statistical model indicated significant

TABLE XXXVII

AVERAGE RETURN AND TOTAL IRRIGATION APPLICATION FROM A GRAIN SORGHUM SIMULATION TRIAL USING DOUBLED RAINFALL FOR THREE LEVELS OF C/L RATIO.

Method of Scheduling	Return $/ha	Method of Scheduling	Irrigation cm
Low Irrigation Cost/High Crop Value			
GS0	743.63	FCSTM	11.33
GS1	743.52	FCSTL	12.42
GS3	738.82	GS13	14.92
GS13	738.75	GS3	14.92
FCSTL*	735.85	GS0	15.21
FCSTM**	729.18	GS1	15.24
Typical Irrigation Cost/Crop Value			
GS0	350.52	FCSTM	8.83
GS1	350.43	FCSTL	11.56
GS3	348.52	GS13	14.92
GS13	348.48	GS3	14.92
FCSTM	346.20	GS0	15.21
FCSTL	343.68	GS1	15.24
High Irrigation Cost/Low Crop Value			
FCSTL	158.09	FCSTM	6.80
FCSTM	157.40	FCSTL	7.50
GS0	153.97	GS13	14.92
GS1	153.89	GS3	14.92
GS3	153.37	GS0	15.21
GS13	153.35	GS1	15.24

*Probabilistic Forecast - Last Plant Scheduling
**Probabilistic Forecast - Middle Plant Scheduling

TABLE XXXVIII

SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES FOR RETURN AND TOTAL IRRIGATION APPLICATION FOR A GRAIN SORGHUM SIMULATION TRIAL USING DOUBLED RAINFALL FOR VARIOUS C/L RATIOS

Low Irrigation Cost/High Crop Value

Significant Factor		Return $/ha	Significant Factor	Irrigation cm
Years:			Years:	
Dry		765.92	Dry	19.29
Wet		710.67	Wet	8.72
Within Years				
Dry Year: Method of Scheduling				
GS0	A*	773.40		
GS1	A	773.19		
GS3	A	769.99		
GS13	A	769.94		
FCSTM	B	758.41		
FCSTL	B	750.57		

Typical Irrigation Cost/Crop Value

Significant Factor	Return $/ha	Significant Factor	Irrigation cm
None		Years:	
		Dry	18.56
		Wet	8.33

TABLE XXXVIII (Continued)

High Irrigation Cost/Low Crop Value					
Significant Factor		Return $/ha	Significant Factor		Irrigation cm
Years:			Years:		
Dry		148.44	Dry		17.36
Wet		161.58	Wet		7.50
Within Years			Method of Scheduling		
Wet Year:			GS1	A*	15.24
Net Application			GS0	A	15.21
			GS3	A	14.92
7.5		165.46	GS13	A	14.92
2.5		157.69	FCSTL	B	7.50
Method of Scheduling			FCSTM	B	6.80
FCSTL	A*	170.47			
FCSTM	A	169.64			
GS0	B	157.49			
GS1	B	157.47			
GS3	B	157.22			
GS13	B	157.20			

*Means with the same letter are not significantly different at the 5% confidence level.

differences due to years for both return and total irrigation application with the exception of return for the typical C/L ratio. Returns for the high irrigation cost/low crop value also showed wet years to have the highest return. Although wetter years are normally thought of as better crop production years, this is the first time wet years returned the higher amount. The return for wet years, in this case, is due to several instances of no irrigation application. No irrigation requirement for 1986 helped offset the reduced income due to the lower yields of the late planted crop. The total irrigation application in dry years is approximately twice the wet year application.

Wet years for the low irrigation cost/high crop value showed significant differences in returns favoring stage of growth methods. Wet years comparisons for the high irrigation cost/low crop value ratio depended on net application and method of scheduling. The 7.5 cm net application returned more than the 2.5 cm net application. FCSTL and FCSTM had higher returns than did the stage of growth methods.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Irrigated agricultural production contributes significantly to the national economy and impacts certain local and regional economies to an even greater extent. Irrigated agriculture requires a substantial investment of water and energy resources, particularly in areas dependent on groundwater. Improvements in irrigation water management have helped to maintain a vital and viable irrigated agriculture. However, other improved irrigation management techniques may still be unidentified. These could include more optimal methods for scheduling irrigation.

Irrigation scheduling is the determination of when and how much irrigation water to apply to meet specific management objectives. In today's economic climate, a goal of best net return is common.

One factor that is often difficult to evaluate in determining an irrigation schedule is the effect of uncertain future events. The likelihood of rainfall is one uncertain event that may play an important role in deciding whether irrigation should begin or be delayed. The effect of the decision on yield is not precisely known. An estimate of the effect of a current decision on future yield is now possible with the development of crop growth simulation models.

A grain sorghum crop growth simulation model was combined with a calculated risk decision-making process to determine optimal irrigation schedules. The calculated risk concept used is as follows:

If:	Then:
$P > C/L$	Protect
$P = C/L$	Either course
$P < C/L$	Do not protect

where for this study:

P = the probability of no rainfall,

C = the daily cost of irrigation,

L = the daily loss in value of crop yield due to insufficient soil water.

The probability of a loss due to no rainfall was calculated by subtracting the probability of rainfall from one. Three general classes of estimating rainfall probability were examined, which were (1) climatological forecasts, (2) probabilistic forecasts, and (3) the perfect forecast. Climatological rainfall forecasts developed included the daily climatological probability, the conditional daily climatological probability, and daily and conditional daily probability for rainfall greater than 0.635 cm. Probabilistic rainfall forecasts developed included the probabilistic forecast, comparative probabilistic forecast, conditional comparative forecast, and the latter two forecasts for rainfall greater than 0.635 cm. The perfect forecast was developed by examining rainfall records and recording either a 100% probability (rainfall occurred) or a 0% probability (no rainfall occurred). Rainfall probability estimates using these three forecast classes were prepared for four growing seasons.

Comparisons of two general categories of irrigation scheduling methods were made using return (defined as income minus irrigation pumping costs) and total net irrigation application. The first scheduling category was based on soil water level and stage of growth restriction. The second scheduling category was based on a risk analysis decision-making process where irrigation water was applied only when the ratio of the cost of applying irrigation (C) to the loss in crop value (L) was less than the probability of no rainfall occurrence. The various rainfall forecasts were used in a grain sorghum crop growth simulation model to generate data for three C/L ratios.

Two procedural methods for scheduling the C/L decision-making trials were developed to account for differences in yield across a field due to the time interval required for irrigation. These are referred to as middle plant and last plant methods. These methods projected soil water levels into the future and entered these projections into the irrigation scheduling decision-making process.

A final comparison was made using selected scheduling methods and doubled rainfall magnitude to estimate effects on the scheduling process for this crude approximation of a more humid environment.

Statistical comparisons of return and total irrigation application were made. The grain sorghum model utilized for this study was deterministic, so repeated trials for any given set of starting parameters would result in identical results. To make a between years comparison, a division between years was made based on total growing season rainfall.

Analysis of variance tests were performed on the data for the three risk analysis ratios. Statistical significance was based on a 5% confidence level. The statistical model included comparison for years, net irrigation application, method of scheduling and all possible interactions.

The trends of other production parameters were also noted for each of the three C/L risk analysis ratios as an aid in understanding the effects of the scheduling method. These trends were not included as a part of the doubled rainfall simulation study.

Conclusions

General Trends

Considering only return, it is apparent that the stage of growth scheduling methods (especially GS0 and GS1) are the superior scheduling methods. Stage of growth scheduling methods lead all methods in return for each of the C/L ratios.

The stage of growth scheduling methods are not affected by the C/L ratio and consequently apply an identical amount of irrigation water regardless of the ratio. The C/L methods apply decreasing water amounts with increasing C/L ratios. The C/L methods apply approximately half the amount of irrigation water that growth stage methods apply for the high irrigation cost/low crop value ratio. The tendency of the C/L ratio scheduling methods to apply less water than growth stage methods may be an important consideration when evaluating various methods. For full irrigation programs, when irrigation costs are small relative to crop value, the growth stage method appears to be the better management choice. The C/L methods may be the better choice for scheduling when irrigation water is limited by supply or institutional constraints and irrigation costs are high relative to crop value.

The C/L methods associated with critical rainfall values, the probabilistic forecast, and the perfect forecast appear to be scheduling methods that have better returns than other C/L methods and have less total irrigation application than growth stage methods. The perfect forecast did not result in a superior schedule. It always made technically correct decisions, i.e., delaying irrigation on days with rainfall, but many of these technically correct decisions for practical purposes were incorrect due to the frequency of very small rainfall events. Small rainfall events do not sufficiently restore soil water to prevent yield limitations.

The simulation trials conducted using doubled rainfall indicated that differences in returns among scheduling methods were negligible. This is partially due to the reduced irrigation requirements which would tend to dampen the irrigation effects. However, larger rainfall amounts would better reward the C/L method for delaying an irrigation based on a favorable forecast. The C/L methods have higher return and less irrigation requirement for the high irrigation cost/low crop value ratio. This indicates that the C/L method may have more advantage in humid climates and also where water supplies are limited. The major weakness of the doubled rainfall simulation is that no accounting for rainfall frequency differences is made.

Statistical Analysis

No differences in return due to scheduling methods were indicated for any of the three C/L ratios. The analysis indicated that return is dependent on years. The difference due to years is expected since each year has unique production influences. The decisions for both growth stage and C/L methods are made on a daily basis, which means the overall yearly effect on production has no direct influence on the daily decision. Conclusions drawn disregarding yearly differences are the same as conclusions drawn from within year comparisons across C/L ratios.

Total irrigation application obviously varies with years. However, as with return, the difference due to years is negated by the daily decision-making process. Growth stage scheduling methods apply significantly more water than the C/L methods for typical and high irrigation cost/low crop value ratios.

Net irrigation application is identified as having an effect on total seasonal irrigation application at all C/L levels. This effect is reasonable, regardless of scheduling method, since a smaller net application amount provides more opportunities to make decisions based on the scheduling criteria. The opportunity to make more irrigation decisions for the 2.5 net application offsets a potential disadvantage of having more soil evaporation due to more frequent irrigation application. The scheduling procedure performed for each net application amount and can be used for any system type, providing proper accounting of costs associated with irrigation occurs.

The C/L risk analysis decision-making process appears to have merit in determining irrigation schedules. Returns from the C/L methods are not statistically different from growth stage methods used to represent improved irrigation scheduling practices. The C/L methods clearly apply less irrigation water for increasingly adverse C/L ratios.

Recommendations

Recommendations for further study are as follows:

1) Investigate additional crop types. Grain sorghum was selected for this investigation since its elastic water demand fits the semi-arid growing conditions of the study site. The C/L scheduling method may be more appropriate for water sensitive crops or those with a more clearly defined critical stage(s) of growth.

2) Investigate additional climates. The doubled rainfall analysis suggests the C/L method may perform better in a more humid environment.

3) Investigate additional forecast methods associated with the rainfall amounts. The perfect forecast was not a superior scheduling method due to the relatively high frequency of very small rainfall events. Additional simulations, using historical rainfall to develop perfect forecasts for various critical rainfall amounts, may indicate the merits of these types of forecasts. This may also be a function of climatic conditions.

4) Investigate simulation methodologies and extended-term rainfall forecasts to extend the irrigation decision-making process beyond the daily basis.

5) Investigate the C/L risk analysis decision-making process in conjunction with stochastic crop models. The C/L method tends to initiate irrigation at lower soil water levels than the growth stage methods (the growth stage

methods also include a soil water depletion criterion). Stochastic simulations would provide a more complete understanding of the variability associated with the decision-making process.

6) Conduct field investigations to confirm simulation conclusions.

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APPENDIX A

MODEL INPUT PARAMETERS

TABLE XXXIX

MODEL INPUT PARAMETERS FOR 1984 THROUGH 1987

Parameter	Input Value		Definition
N	19		Maximum Number of Leaves
ROSPZ	66		Row Spacing, cm
P	87728	(1984)	Population, Plants/ha
	77398	(1985)	
	210000	(1986)	
	87728	(1987)	
ALT	36.5		Latitude, degrees N
SW	17.26		Beginning Soil Water Level, cm
UL	25.9		Maximum Soil Water Level, cm
SDEPTH	5		Planting Depth, cm
MO, ND, IYR	6, 4, 84		Planting Date, 1984
	5, 17, 85		Planting Date, 1985
	6, 17, 86		Planting Date, 1986
	5, 19, 87		Planting Date, 1987
XMAX(1)	0.46		Maximum Leaf Area, cm^2
XMAX(2)	3.70		
XMAX(3)	5.39		
XMAX(4)	8.26		
XMAX(5)	10.9		
XMAX(6)	13.51		
XMAX(7)	22.91		
XMAX(8)	36.27		
XMAX(9)	67.81		
XMAX(10)	119.16		
XMAX(11)	172.15		
XMAX(12)	247.49		
XMAX(13)	308.79		
XMAX(14)	328.3		
XMAX(15)	347.83		
XMAX(16)	339.87		
XMAX(17)	269.13		
XMAX(18)	162.64		
XMAX(19)	55.89		

APPENDIX B

1984 THROUGH 1987 AND HISTORICAL AVERAGE WEATHER RECORDS

TABLE XL

1984 WEATHER DATA FOR GOODWELL, OK.

Calendar Day	Temperature °C Maximum	Minimum	Solar Radiation Ly/day	Rainfall cm
149	19.37	9.14	621.9	0.0
150	25.73	5.34	723.0	0.0
151	30.76	10.57	675.1	0.0
152	37.63	16.29	707.0	0.0
153	35.49	16.72	669.1	0.0
154	22.57	10.53	571.1	0.1
155	26.37	13.34	466.2	0.0
156	33.54	13.80	709.0	0.0
157	34.71	17.02	633.1	0.0
158	31.20	13.26	695.5	0.0
159	35.06	18.43	717.0	0.0
160	33.34	10.90	741.0	0.0
161	29.25	15.39	723.0	0.0
162	28.21	14.17	294.7	0.0
163	29.91	16.33	415.2	0.6
164	34.99	17.28	723.0	0.0
165	34.22	18.79	598.5	0.0
166	30.46	16.11	573.9	0.0
167	32.94	16.63	623.3	0.0
168	32.54	17.63	611.0	0.7
169	34.08	18.88	597.2	0.0
170	23.76	17.54	262.0	0.0
171	28.73	15.18	438.6	0.0
172	32.15	17.99	541.4	0.0
173	36.21	18.79	520.6	0.0
174	37.48	18.79	683.9	0.0
175	30.39	19.37	489.4	0.0
176	31.33	16.16	481.3	0.0
177	37.63	18.88	671.6	0.3
178	35.34	17.06	684.5	0.1
179	31.01	18.25	661.4	0.0
180	38.10	15.52	662.6	0.1
181	34.02	16.63	721.0	0.0
182	33.88	16.63	707.0	0.0
183	32.48	18.74	496.4	0.0
184	34.85	16.42	661.3	0.0
185	37.10	18.25	633.7	0.7
186	28.84	17.28	592.9	0.0
187	36.06	16.76	564.4	0.0
188	38.56	15.43	738.0	0.1
189	38.17	21.27	716.0	0.0
190	38.41	18.25	728.0	0.0
191	37.94	19.78	705.0	0.0

TABLE XL (Continued)

Calendar Day	Temperature °C Maximum	Minimum	Solar Radiation Ly/day	Rainfall cm
192	36.50	19.47	546.3	0.5
193	31.39	18.30	588.2	0.3
194	33.67	15.31	697.8	0.0
195	36.36	18.12	635.7	0.0
196	38.49	21.04	694.3	0.0
197	34.29	19.10	439.0	0.6
198	29.55	17.41	649.9	0.1
199	32.02	16.46	629.3	0.0
200	34.29	16.03	695.0	0.0
201	37.10	18.65	658.9	0.0
202	37.18	16.80	695.1	0.0
203	37.25	19.01	667.4	0.0
204	36.80	20.29	627.9	0.0
205	37.03	18.43	637.3	0.0
206	33.00	16.42	622.9	0.0
207	30.21	15.47	447.3	0.0
208	34.92	16.46	600.4	0.1
209	32.02	17.72	519.2	0.0
210	29.43	18.30	457.4	0.0
211	33.54	17.37	604.8	0.0
212	34.85	19.10	628.8	0.0
213	35.49	18.16	544.4	0.0
214	33.47	17.85	582.1	0.0
215	33.34	17.06	553.2	0.0
216	35.63	17.28	654.9	0.0
217	36.73	20.43	541.2	0.4
218	34.64	18.79	520.9	0.2
219	36.65	20.38	539.5	0.0
220	34.15	19.15	389.7	0.1
221	29.14	18.92	271.9	0.1
222	30.52	18.56	454.3	0.0
223	20.94	17.85	170.6	0.7
224	28.73	17.59	473.3	0.0
225	30.95	15.69	573.3	0.0
226	31.58	16.29	605.7	0.0
227	33.20	17.81	557.7	0.0
228	33.61	19.47	524.5	0.6
229	33.27	18.12	569.8	0.0
230	34.92	18.34	641.9	0.0
231	33.95	19.01	614.5	0.0
232	33.14	18.07	595.1	0.0
233	37.94	20.66	594.6	0.0
234	31.39	20.15	599.1	0.0
235	31.01	20.25	377.6	0.0
236	29.31	18.43	315.6	0.1
237	33.54	19.01	535.9	0.0

TABLE XL (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
238	34.08	19.74	541.2	0.0
239	35.34	19.97	600.9	0.0
240	36.95	18.25	586.3	0.0
241	39.04	17.41	601.7	0.0
242	39.85	18.52	593.2	0.0
243	38.72	15.99	565.2	0.0
244	35.70	20.06	598.7	0.0
245	35.56	18.74	559.9	0.0
246	25.52	15.77	495.2	2.9
247	27.75	12.03	601.4	0.0
248	30.27	12.72	591.6	0.0
249	33.34	14.55	584.5	0.0
250	34.15	17.68	587.4	0.0
251	35.85	17.54	587.7	0.0
252	29.73	12.56	570.8	0.0
253	33.74	13.22	563.8	0.0
254	38.17	15.22	547.1	0.0
255	36.21	17.72	511.3	0.0
256	36.36	21.27	540.1	0.0
257	34.02	20.57	527.5	0.0
258	21.66	14.93	178.9	0.0
259	19.74	10.98	300.8	0.0
260	26.21	14.80	296.7	0.0
261	31.58	16.76	442.2	0.0
262	31.26	9.57	529.6	0.0
263	32.02	12.93	527.1	0.0
264	31.58	11.66	523.1	0.0
265	28.32	12.40	480.5	0.0
266	30.76	14.55	496.7	0.0
267	34.36	16.29	437.6	0.0
268	35.20	12.19	488.7	0.0
269	15.94	4.60	465.2	0.0
270	9.85	5.41	169.7	0.2
271	7.91	5.22	76.4	0.1
272	6.86	0.17	98.6	0.1
273	8.50	-0.02	230.6	0.5
274	20.66	-0.32	463.3	0.0
275	23.16	7.83	349.8	0.0
276	31.33	12.23	447.6	0.0
277	25.52	13.30	209.4	0.0
278	22.09	12.81	260.7	0.5
279	24.94	7.95	445.6	0.0
280	24.63	12.07	334.3	0.1
281	26.70	9.14	407.4	0.0
282	23.56	7.83	388.9	1.0
283	19.88	11.91	267.4	1.0

TABLE XLI

1985 WEATHER DATA FOR GOODWELL, OK.

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
137	23.33	11.11	502.9	0.0
138	17.78	8.89	251.8	0.0
139	23.89	7.78	487.9	0.0
140	26.67	9.44	502.1	0.0
141	24.44	12.78	511.9	0.0
142	20.56	7.22	281.4	0.0
143	19.44	8.89	366.2	0.0
144	25.56	10.00	637.2	7.5
145	28.89	11.67	627.4	0.0
146	31.11	12.78	625.9	0.0
147	33.89	12.22	598.6	0.0
148	30.00	15.56	615.0	0.0
149	31.67	12.22	620.3	0.0
150	36.67	13.33	599.4	0.0
151	34.44	10.56	653.5	0.0
152	29.44	13.33	525.6	0.0
153	32.78	15.56	639.1	0.0
154	25.56	13.89	619.9	0.0
155	22.78	13.89	265.1	0.0
156	16.67	12.22	166.5	0.3
157	17.22	12.78	211.7	3.4
158	28.89	16.11	625.8	0.1
159	36.11	19.44	596.3	0.0
160	37.78	16.67	597.4	0.0
161	27.78	13.89	525.0	0.0
162	35.56	11.67	536.5	0.0
163	25.00	11.11	672.7	1.0
164	22.78	12.22	507.9	0.0
165	30.56	14.44	609.0	0.0
166	36.11	16.11	608.1	0.0
167	33.33	13.33	566.9	0.2
168	36.67	18.89	520.0	0.0
169	28.89	14.44	599.5	0.0
170	26.11	11.67	594.9	0.0
171	30.56	15.56	499.8	0.0
172	35.00	18.89	650.4	0.0
173	36.67	13.33	568.0	0.0
174	32.22	17.22	646.6	0.0
175	37.22	17.22	619.5	0.0
176	35.00	18.89	629.2	0.0
177	32.22	16.67	389.3	0.0
178	25.56	8.89	529.3	0.0
179	27.78	10.00	651.4	0.0
180	33.89	15.00	629.5	0.0

TABLE XLI (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
181	32.22	17.78	600.0	0.0
182	28.89	11.67	530.6	0.0
183	28.89	15.56	558.2	0.0
184	30.00	13.89	580.9	0.3
185	31.11	13.89	640.7	0.0
186	30.00	14.44	594.5	0.0
187	29.44	15.00	627.5	0.0
188	31.11	15.00	612.9	0.0
189	31.11	15.00	632.3	0.0
190	28.89	13.89	613.6	0.0
191	36.95	19.15	584.6	0.0
192	38.49	20.71	640.7	0.0
193	38.49	20.99	576.7	0.0
194	40.34	21.04	630.4	0.0
195	38.17	19.56	609.3	0.4
196	30.52	18.12	538.4	0.1
197	34.64	15.35	559.2	0.0
198	38.49	20.71	622.7	0.0
199	39.93	19.97	606.2	0.0
200	36.36	20.20	476.7	0.1
201	34.71	17.37	440.7	0.0
202	36.21	18.74	506.5	0.0
203	33.81	19.24	441.0	0.0
204	34.64	17.81	451.7	0.0
205	29.73	17.33	231.8	0.2
206	31.64	17.46	581.8	0.0
207	32.02	14.97	528.3	0.0
208	33.74	16.50	489.2	0.0
209	38.49	20.01	580.4	0.8
210	33.34	18.38	475.9	0.0
211	37.48	18.88	525.0	0.0
212	33.47	20.90	531.9	0.0
213	30.03	17.94	303.2	1.7
214	33.61	18.21	528.5	0.3
215	36.50	20.57	514.0	0.0
216	32.74	17.81	509.8	0.0
217	35.49	17.63	616.8	0.0
218	40.09	18.52	563.4	0.0
219	37.03	18.38	583.2	0.0
220	37.94	18.30	602.2	0.0
221	38.64	17.99	534.8	0.0
222	30.21	14.76	575.0	0.0
223	35.27	20.85	471.0	0.0
224	34.43	21.51	545.5	0.0
225	34.99	17.85	549.9	0.0
226	24.27	15.18	216.4	0.0

TABLE XLI (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
227	29.31	16.85	426.1	0.0
228	35.99	15.35	546.9	0.0
229	32.15	18.88	584.6	0.0
230	35.13	17.28	490.1	0.2
231	28.09	16.72	278.0	0.0
232	36.06	16.67	531.7	0.0
233	37.33	19.24	481.2	0.0
234	36.43	17.68	572.1	0.0
235	31.14	18.25	284.3	0.0
236	29.73	15.56	527.7	0.0
237	34.02	14.00	472.3	0.0
238	34.02	15.60	541.3	0.0
239	36.06	14.88	557.0	0.0
240	36.80	20.06	529.6	0.0
241	38.80	20.38	534.0	0.0
242	39.77	21.09	551.5	0.0
243	37.94	18.47	568.8	0.0
244	36.95	19.83	513.0	0.0
245	36.36	19.69	501.1	0.0
246	37.86	20.01	530.2	0.2
247	34.15	18.61	510.1	0.1
248	36.50	16.93	522.6	0.0
249	36.73	16.72	528.4	0.0
250	36.36	14.76	546.2	0.0
251	34.64	16.11	501.1	0.0
252	34.50	17.24	367.8	0.0
253	35.27	16.50	404.2	0.0
254	22.67	16.11	118.3	5.9
255	26.54	16.11	298.0	1.3
256	27.59	16.76	410.8	0.0
257	20.25	16.03	101.6	0.0
258	25.78	15.99	426.3	0.0
259	31.26	17.37	473.4	0.0
260	33.95	16.37	499.6	0.0
261	30.33	17.11	362.3	2.1
262	25.94	16.80	313.3	3.1
263	19.47	7.44	65.4	0.7
264	20.57	6.58	364.8	0.1
265	23.71	8.11	391.2	0.5
266	17.24	4.25	485.0	0.0
267	18.52	6.50	355.5	0.0
268	18.70	8.27	466.5	0.0
269	21.46	7.01	455.8	0.0
270	27.92	8.62	473.0	0.0
271	17.06	1.94	255.0	0.6
272	4.48	-0.59	166.6	2.4

TABLE XLII

1986 WEATHER DATA FOR GOODWELL, OK.

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
135	27.25	7.09	587.2	0.0
136	25.46	7.91	576.2	0.0
137	12.68	6.90	136.0	0.0
138	25.84	3.44	674.4	0.0
139	32.87	10.53	640.3	0.0
140	33.54	10.41	670.6	0.0
141	33.81	12.32	611.6	0.0
142	37.48	13.67	604.1	0.0
143	26.26	13.22	534.4	0.0
144	28.38	13.96	284.2	0.3
145	22.43	10.25	439.3	0.1
146	20.11	8.78	215.4	1.7
147	22.04	8.23	442.0	0.1
148	21.56	10.29	350.1	0.0
149	26.21	10.78	425.4	0.3
150	27.31	11.70	443.8	0.0
151	28.84	13.92	392.6	0.2
152	24.17	14.59	298.8	1.6
153	27.59	16.07	386.7	1.0
154	30.15	15.69	541.6	0.0
155	31.64	16.20	657.1	0.0
156	31.39	15.94	552.5	0.0
157	36.95	16.11	613.1	0.0
158	34.15	17.50	638.2	0.3
159	32.15	16.11	558.4	0.4
160	27.98	16.50	413.3	1.6
161	25.36	13.71	633.0	0.0
162	29.08	12.23	685.3	0.0
163	36.43	12.36	638.5	0.0
164	35.63	16.03	652.0	0.0
165	35.56	15.90	647.4	0.1
166	36.88	16.80	647.8	0.4
167	36.06	17.37	616.5	0.0
168	30.89	15.82	517.2	0.0
169	30.95	17.24	480.7	0.0
170	34.99	18.34	545.4	0.0
171	37.33	19.28	461.8	0.0
172	35.63	19.19	579.2	0.0
173	37.48	19.28	586.0	0.4
174	36.58	19.10	552.2	0.0
175	35.85	18.25	521.4	0.0
176	34.71	17.81	582.4	0.0
177	34.92	17.37	536.9	0.0
178	36.80	18.38	592.1	0.1

TABLE XLII (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
179	38.80	16.67	682.9	0.0
180	40.93	19.37	606.8	0.0
181	42.84	21.61	490.4	3.0
182	31.83	19.74	494.9	0.0
183	33.61	19.28	660.7	0.0
184	35.63	18.88	636.6	0.0
185	39.28	20.90	633.6	0.0
186	39.93	22.92	461.9	1.1
187	27.08	16.42	343.1	0.0
188	33.34	17.28	498.3	0.0
189	36.21	20.94	640.7	0.0
190	37.33	18.79	575.8	0.0
191	37.18	20.71	570.4	0.2
192	37.40	16.98	639.3	0.0
193	36.14	21.42	640.6	0.0
194	38.88	19.65	479.3	0.0
195	35.49	23.11	641.8	0.0
196	35.99	20.76	654.9	0.0
197	37.71	22.33	603.8	0.0
198	38.88	22.62	609.0	0.1
199	39.44	21.99	657.5	0.0
200	42.31	20.06	634.2	0.0
201	31.83	18.70	395.1	0.7
202	31.01	17.06	466.2	0.1
203	35.63	18.21	578.1	0.0
204	36.14	18.92	632.3	0.0
205	40.76	19.47	635.0	0.0
206	40.18	20.15	549.6	0.5
207	39.68	16.29	594.4	0.0
208	41.10	21.85	628.3	0.0
209	41.44	17.68	667.2	0.0
210	43.11	20.66	648.2	0.0
211	41.35	22.92	640.1	0.0
212	38.72	21.66	418.9	0.0
213	40.68	20.76	473.3	0.0
214	33.88	17.76	549.3	0.2
215	34.02	16.07	557.8	0.9
216	34.22	16.93	602.1	0.0
217	37.56	18.16	613.4	0.0
218	36.95	17.76	591.0	0.4
219	38.49	18.92	599.4	0.0
220	32.09	17.99	431.6	1.1
221	36.14	19.37	582.7	0.0
222	33.95	16.46	565.9	0.0
223	35.41	18.03	585.8	0.0
224	35.63	18.65	587.7	0.0

TABLE XLII (Continued)

Calendar Day	Temperature °C Maximum	Minimum	Solar Radiation Ly/day	Rainfall cm
225	36.80	21.18	379.7	0.2
226	30.64	19.33	199.4	1.9
227	32.87	19.01	561.9	0.0
228	36.88	18.12	577.6	0.0
229	38.10	19.37	595.8	0.0
230	39.28	19.19	590.2	0.0
231	37.48	21.18	577.6	0.0
232	37.25	18.92	535.9	0.3
233	29.08	17.54	354.9	0.2
234	34.43	17.85	374.6	0.0
235	32.22	19.60	404.9	0.0
236	34.92	17.28	479.4	0.0
237	33.67	17.50	491.3	0.0
238	37.33	18.43	469.0	0.8
239	26.00	14.93	336.0	0.0
240	27.92	11.18	539.1	0.0
241	28.96	14.97	391.3	0.0
242	24.94	18.79	115.4	0.2
243	19.83	15.64	100.3	0.0
244	23.56	14.88	151.3	0.1
245	31.01	17.02	488.2	0.0
246	33.40	16.46	383.1	0.0
247	29.85	15.01	462.4	0.0
248	31.14	12.44	506.0	0.0
249	29.97	10.66	385.9	0.0
250	14.25	8.82	140.7	0.0
251	28.04	10.49	399.6	0.0
252	35.49	16.63	499.4	0.0
253	35.63	18.83	445.5	0.0
254	29.14	10.86	525.4	0.0
255	31.07	9.85	515.8	0.0
256	33.47	13.05	446.0	0.0
257	33.14	18.38	416.4	0.0
258	38.10	16.72	463.8	0.0
259	33.74	17.94	465.8	0.0
260	35.99	14.71	509.7	0.0
261	35.85	14.09	471.8	0.0
262	36.95	19.56	471.4	0.0
263	35.27	17.94	477.3	0.0
264	34.57	17.54	460.7	0.0
265	36.36	20.15	403.5	0.3
266	34.85	17.68	358.2	0.1
267	28.61	15.94	409.4	0.0
268	28.96	9.73	470.8	0.0
269	30.70	11.99	470.7	0.0
270	30.64	7.20	467.2	0.0

TABLE XLII (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
271	32.74	16.85	335.2	0.1
272	23.41	12.32	238.4	0.1
273	20.25	9.85	308.4	0.0
274	29.67	10.94	394.6	0.0
275	24.32	17.63	100.7	0.0
276	25.52	12.19	351.6	0.0
277	21.99	8.07	409.8	0.0
278	23.86	6.47	234.7	0.0
279	24.78	6.27	409.9	0.0
280	27.75	9.22	415.1	0.0
281	29.73	11.22	404.3	0.0
282	15.94	9.97	72.9	0.0
283	17.06	9.97	87.1	0.0
286	20.52	-3.74	410.7	0.0
287	22.87	2.44	401.3	0.0
288	22.87	2.94	388.3	0.0
289	27.08	5.69	327.2	0.0
290	26.59	4.48	390.6	0.0
291	25.57	5.38	350.8	0.0
292	19.83	12.15	139.7	0.0
293	17.72	9.69	96.5	0.0
294	13.47	11.30	43.3	1.3
295	22.43	6.15	366.4	0.0
296	19.37	5.96	288.2	0.0
297	18.61	5.53	315.4	0.0
298	20.57	3.83	322.1	0.0
299	20.01	2.79	350.6	0.0
300	26.86	5.69	346.4	0.0
301	24.84	5.57	346.5	0.0
302	21.89	3.67	304.0	0.0
303	23.76	7.64	314.1	0.0
306	4.14	0.02	43.1	0.8
307	12.11	4.14	108.1	0.3
308	7.36	2.63	42.1	3.8
309	19.24	-0.17	319.9	0.0
310	19.33	3.29	317.3	0.0

TABLE XLIII

1987 WEATHER DATA FOR GOODWELL, OK.

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
139	30.56	15.00	611.0	0.0
140	23.33	14.44	314.0	0.9
141	21.11	10.00	307.0	1.2
142	23.33	8.33	642.0	0.3
143	15.56	12.78	243.0	0.2
144	20.56	10.00	333.0	0.0
145	23.89	7.78	182.0	0.9
146	26.67	7.22	630.0	0.4
147	19.44	10.00	198.0	0.9
148	26.11	11.67	506.0	0.0
149	21.11	7.22	325.0	0.0
150	27.22	7.78	678.0	0.0
151	27.78	14.44	652.0	1.5
152	28.33	12.78	633.0	0.0
153	30.00	12.78	607.0	0.0
154	26.67	12.78	677.0	0.4
155	22.22	8.33	520.0	0.0
156	25.00	11.11	675.0	0.0
157	27.78	12.22	748.0	0.0
158	31.67	14.44	707.0	0.0
159	30.00	16.67	608.0	0.0
160	28.89	14.44	594.0	0.0
161	22.78	17.22	333.0	0.6
162	28.89	17.78	498.0	0.0
163	32.22	14.44	669.0	0.3
164	32.22	13.33	674.0	0.0
165	35.00	15.56	730.0	0.2
166	33.89	16.67	574.0	0.0
167	35.56	16.67	632.0	0.0
168	40.68	22.92	165.0	0.0
169	33.34	13.96	605.1	0.0
170	31.58	15.69	617.7	0.1
171	34.02	16.89	700.0	1.1
172	31.64	16.03	637.1	2.7
173	32.28	15.22	724.0	0.0
174	33.40	18.52	718.0	0.0
175	30.15	15.60	432.2	3.1
176	28.96	16.46	724.0	0.0
177	30.03	16.85	421.7	0.0
178	33.67	17.54	724.0	0.0
179	33.54	18.97	711.0	0.0
180	28.96	18.38	478.5	0.0
181	27.64	16.59	424.1	0.1
182	34.29	14.30	585.7	1.6

TABLE XLIII (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
183	31.70	19.60	633.6	0.0
184	30.76	19.19	532.3	0.2
185	32.41	16.93	720.0	0.0
186	33.95	16.11	724.0	0.0
187	37.48	16.50	734.0	0.0
188	38.10	20.80	655.9	0.1
189	33.67	17.63	546.3	0.0
190	34.57	19.51	643.7	0.0
191	36.65	17.99	684.6	0.0
192	39.93	21.56	647.3	0.2
193	26.54	14.93	270.3	0.0
194	29.67	11.83	693.6	0.0
195	31.01	15.35	304.0	2.0
196	32.35	13.18	719.0	0.0
197	33.61	19.01	696.7	0.0
198	35.13	19.47	594.7	0.0
199	37.18	16.33	743.0	0.0
200	37.71	21.70	677.8	0.0
201	34.92	18.65	654.5	0.0
202	34.50	18.56	678.7	0.0
203	34.64	19.65	654.1	0.0
204	36.65	20.43	668.7	0.0
205	36.14	20.66	681.6	0.0
206	35.63	18.30	640.4	0.0
207	35.77	19.92	692.4	0.0
208	35.56	18.74	668.1	0.0
209	35.99	18.88	685.7	0.0
210	36.36	20.80	688.0	0.0
211	37.71	20.25	689.3	0.0
212	38.25	20.34	694.6	0.0
213	39.85	21.46	680.1	0.0
214	41.87	60.70	675.1	0.0
215	41.35	21.94	608.8	0.0
216	29.97	18.61	295.7	0.4
217	36.65	16.46	646.1	0.0
218	41.10	20.62	662.1	0.0
219	38.72	22.33	551.1	0.0
220	34.50	21.04	485.8	0.0
221	25.89	18.07	208.2	0.2
222	33.54	17.72	576.9	0.0
223	36.73	20.38	588.4	0.0
224	35.63	18.47	277.1	0.1
225	30.64	17.68	516.3	0.0
226	39.85	20.11	647.5	0.0
227	38.49	19.42	649.9	0.0
228	36.88	16.98	653.8	0.0

TABLE XLIII (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day	Rainfall cm
229	41.10	17.06	657.4	0.0
230	34.85	20.11	626.3	0.0
231	39.77	18.30	565.3	0.0
232	39.44	22.18	629.1	0.0
233	40.34	23.41	617.0	0.0
234	32.28	18.34	470.7	0.0
235	18.34	12.40	88.9	1.4
236	27.81	13.38	348.9	0.0
237	31.83	18.25	376.3	4.5
238	25.20	16.76	185.3	0.1
239	23.11	14.55	264.3	0.2
240	27.08	11.06	548.1	0.0
241	29.85	13.67	520.5	0.2
242	34.02	14.97	629.1	0.1
243	30.03	12.85	549.7	0.0
244	36.88	14.93	591.1	0.0
245	36.43	14.17	572.1	0.0
246	35.13	16.42	593.4	0.0
247	33.27	16.07	417.3	0.0
248	22.97	16.54	200.5	0.3
249	31.51	16.42	339.6	0.0
250	33.20	13.55	411.4	0.2
251	27.64	14.34	454.8	1.4
252	33.47	14.51	550.9	0.0
253	33.07	11.66	481.0	0.5
254	29.97	12.56	516.1	1.6
255	23.21	12.19	314.3	0.1
256	34.22	14.17	546.9	0.0
257	24.68	16.54	179.0	0.0
258	30.15	12.03	438.4	0.0
259	35.13	11.46	531.7	0.0
260	28.61	13.18	436.6	1.7
261	25.94	12.89	290.7	1.5
262	27.64	11.38	443.9	0.0
263	27.19	11.42	299.8	0.4
264	27.14	10.01	509.6	0.0
265	29.55	9.38	472.5	0.0
266	34.92	10.33	517.6	0.0
267	33.81	11.18	518.4	0.0
268	31.26	10.45	463.8	0.0
269	31.14	12.64	481.5	0.0
270	31.96	11.75	479.3	0.0
271	29.31	13.26	470.8	0.0
272	32.15	9.50	395.2	0.0
273	31.45	7.68	487.8	0.0
274	37.18	9.38	486.9	0.0

TABLE XLIV

HISTORICAL AVERAGE TEMPERATURE FOR GOODWELL, OK. AND AVERAGE SOLAR RADIATION FOR DODGE CITY, KS.

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day
121	23.0	6.3	520.1
122	22.9	6.1	570.6
123	23.9	7.2	530.0
124	24.6	7.6	501.3
125	26.4	8.7	559.3
126	24.8	7.6	578.9
127	25.2	8.7	603.0
128	25.6	8.7	558.1
129	25.7	8.4	556.2
130	24.6	8.6	527.1
131	25.2	8.3	563.3
132	25.9	7.9	577.5
133	25.2	8.6	580.7
134	25.5	8.9	588.3
135	25.2	9.0	583.9
136	26.1	9.3	567.1
137	25.9	10.0	605.2
138	26.1	10.4	552.8
139	26.1	10.5	558.3
140	27.7	11.1	545.7
141	27.1	10.9	631.6
142	27.6	11.2	553.1
143	26.9	11.5	521.0
144	27.2	11.7	570.8
145	27.8	11.2	600.0
146	27.5	11.1	625.9
147	28.0	10.7	536.3
148	27.3	11.7	612.6
149	28.3	12.3	610.9
150	29.0	12.2	635.2
151	27.5	12.0	556.1
152	27.0	12.1	567.3
153	27.6	12.1	615.1
154	28.0	12.2	613.9
155	28.5	13.0	633.7
156	29.3	12.9	633.0
157	29.7	13.3	612.8
158	31.2	14.0	681.8
159	31.3	14.3	596.3
160	30.6	13.9	652.4
161	29.9	13.8	601.1
162	30.7	13.6	664.3

TABLE XLIV (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day
163	31.0	14.4	643.9
164	31.7	15.4	603.9
165	32.3	15.9	609.1
166	32.4	15.7	606.1
167	31.7	15.8	564.5
168	32.2	15.8	606.0
169	32.6	16.0	680.9
170	31.1	15.6	699.4
171	32.6	15.4	712.4
172	33.4	16.7	627.9
173	33.9	16.4	693.1
174	33.7	16.3	660.2
175	33.7	16.2	661.1
176	32.5	16.4	661.9
177	33.2	15.8	660.2
178	33.9	17.4	645.9
179	34.6	17.8	693.6
180	34.7	18.2	661.9
181	34.4	17.7	646.4
182	34.6	18.4	671.9
183	34.7	17.8	657.9
184	34.6	17.9	654.4
185	34.2	17.4	636.9
186	33.8	17.8	642.2
187	33.6	17.4	605.6
188	34.2	18.2	675.6
189	34.1	18.3	584.5
190	34.1	18.1	637.6
191	34.9	18.4	614.6
192	34.2	18.5	621.4
193	33.5	18.1	614.9
194	34.0	17.9	639.6
195	34.4	17.8	644.0
196	34.7	18.1	596.8
197	34.4	17.9	596.1
198	34.1	17.9	618.4
199	34.6	18.9	574.6
200	34.3	18.5	592.4
201	33.7	18.6	572.8
202	33.6	18.1	630.8
203	33.7	18.1	606.6
204	33.0	18.0	596.4
205	33.5	17.9	576.6
206	33.7	18.4	638.3
207	33.9	18.3	644.8

TABLE XLIV (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day
208	34.4	18.1	606.3
209	33.8	17.9	639.2
210	34.1	18.2	628.1
211	33.8	18.3	653.4
212	33.9	18.4	600.1
213	33.3	17.9	603.9
214	34.1	18.2	638.0
215	33.7	17.2	622.0
216	33.2	17.6	608.7
217	33.4	17.7	631.0
218	34.5	17.9	602.1
219	34.1	18.5	574.5
220	33.5	17.5	596.0
221	33.5	17.6	575.6
222	33.3	17.4	575.3
223	32.1	17.3	593.7
224	32.4	17.0	612.0
225	33.1	17.3	589.8
226	33.2	17.2	544.3
227	32.7	17.0	535.5
228	33.0	17.3	558.7
229	33.6	17.6	554.6
230	32.9	17.5	553.2
231	33.2	16.6	549.6
232	32.1	16.7	531.6
233	32.4	16.6	539.6
234	32.0	16.8	499.3
235	32.6	16.9	524.4
236	32.4	16.4	519.8
237	32.6	15.8	530.2
238	32.8	16.0	550.8
239	33.1	16.4	540.3
240	32.3	16.5	526.0
241	32.5	17.0	539.1
242	32.4	16.9	504.5
243	31.8	16.0	494.4
244	31.6	15.3	480.5
245	31.9	15.3	501.8
246	31.7	15.4	489.7
247	30.7	14.2	469.4
248	31.5	14.5	491.8
249	31.5	15.1	505.8
250	30.8	14.5	510.8
251	30.5	14.1	502.3
252	29.6	14.4	475.3

TABLE XLIV (Continued)

Calendar Day	Temperature °C Maximum	Temperature °C Minimum	Solar Radiation Ly/day
253	29.6	13.8	514.2
254	30.6	14.3	446.0
255	30.4	13.7	500.6
256	29.9	12.8	493.2
257	28.5	12.8	412.8
258	28.0	12.3	434.5
259	28.7	12.2	385.9
260	27.9	11.7	423.6
261	29.5	11.3	447.3
262	29.2	12.4	445.4
263	29.2	12.2	407.3
264	26.8	10.6	471.7
265	26.4	10.4	422.3
266	27.2	10.5	357.7
267	26.8	10.8	388.7
268	26.6	10.3	423.1
269	26.7	9.7	394.5
270	26.8	9.1	417.7
271	26.6	9.9	453.1
272	26.9	9.7	435.0
273	25.4	9.4	432.7
274	26.6	9.7	442.4
275	27.4	8.8	414.2
276	27.5	9.1	416.0
277	25.6	8.8	421.4
278	25.4	8.5	386.0
279	24.9	7.9	406.4
280	25.2	6.2	401.8
281	25.8	7.4	420.4
282	26.1	7.1	401.5
283	24.7	7.1	383.4
284	24.6	7.4	365.5
285	25.2	6.9	378.9
286	24.6	6.7	378.5
287	24.0	5.6	345.9
288	23.7	5.6	352.7
289	23.0	5.3	373.7
290	20.8	5.8	334.3
291	22.8	5.4	307.4
292	22.4	4.4	359.0
293	22.4	5.4	339.9
294	22.7	5.2	370.8
295	22.2	4.6	332.1
296	21.0	3.7	309.3
297	21.0	3.3	333.4

APPENDIX C

YEARLY RESULTS FOR 1984 THROUGH 1987 OF A GRAIN SORGHUM SIMULATION TRIAL

TABLE XLV

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR GSO IRRIGATION SCHEDULING PROCEDURE

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	29.38	6376	217.0	169.5	240.7	759.32
84	7.5	0.066	29.38	6376	217.0	169.5	240.7	338.53
84	7.5	0.033	29.38	6376	217.0	169.5	240.7	128.13
85	7.5	0.132	22.50	6181	274.7	154.3	243.8	752.92
85	7.5	0.066	22.50	6181	274.7	154.3	243.8	344.96
85	7.5	0.033	22.50	6181	274.7	154.3	243.8	140.98
86	7.5	0.132	22.50	5134	228.2	115.4	198.4	614.66
86	7.5	0.066	22.50	5134	228.2	115.4	198.4	275.83
86	7.5	0.033	22.50	5134	228.2	115.4	198.4	106.41
87	7.5	0.132	22.50	6077	270.1	122.6	218.3	739.20
87	7.5	0.066	22.50	6077	270.1	122.6	218.3	338.10
87	7.5	0.033	22.50	6077	270.1	122.6	218.3	137.55
84	2.5	0.132	27.50	6378	231.9	169.8	241.3	764.92
84	2.5	0.066	27.50	6378	231.9	169.8	241.3	343.96
84	2.5	0.033	27.50	6378	231.9	169.8	241.3	133.48
85	2.5	0.132	20.00	6180	309.0	154.5	244.2	759.73
85	2.5	0.066	20.00	6180	309.0	154.5	244.2	351.86
85	2.5	0.033	20.00	6180	309.0	154.5	244.2	147.93
86	2.5	0.132	21.25	5135	241.7	115.6	198.9	618.34
86	2.5	0.066	21.25	5135	241.7	115.6	198.9	279.42
86	2.5	0.033	21.25	5135	241.7	115.6	198.9	109.96
87	2.5	0.132	22.50	6093	270.8	123.0	219.3	741.26
87	2.5	0.066	22.50	6093	270.8	123.0	219.3	339.13
87	2.5	0.033	22.50	6093	270.8	123.0	219.3	138.06

TABLE XLVI

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR GS1 IRRIGATION SCHEDULING PROCEDURE

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	29.38	6370	216.8	169.5	240.8	758.51
84	7.5	0.066	29.38	6370	216.8	169.5	240.8	338.12
84	7.5	0.033	29.38	6370	216.8	169.5	240.8	127.93
85	7.5	0.132	22.50	6181	274.7	154.3	243.8	752.92
85	7.5	0.066	22.50	6181	274.7	154.3	243.8	344.96
85	7.5	0.033	22.50	6181	274.7	154.3	243.8	140.98
86	7.5	0.132	22.50	5131	228.1	115.4	198.6	614.31
86	7.5	0.066	22.50	5131	228.1	115.4	198.6	275.65
86	7.5	0.033	22.50	5131	228.1	115.4	198.6	106.33
87	7.5	0.132	22.50	6077	270.1	122.6	218.3	739.20
87	7.5	0.066	22.50	6077	270.1	122.6	218.3	338.10
87	7.5	0.033	22.50	6077	270.1	122.6	218.3	137.55
84	2.5	0.132	27.50	6375	231.8	169.9	241.6	764.47
84	2.5	0.066	27.50	6375	231.8	169.9	241.6	343.74
84	2.5	0.033	27.50	6375	231.8	169.9	241.6	133.37
85	2.5	0.132	20.00	6210	310.5	155.2	245.3	763.69
85	2.5	0.066	20.00	6210	310.5	155.2	245.3	353.85
85	2.5	0.033	20.00	6210	310.5	155.2	245.3	148.92
86	2.5	0.132	21.25	5135	241.7	115.7	199.1	618.34
86	2.5	0.066	21.25	5134	241.6	115.6	199.1	279.35
86	2.5	0.033	21.25	5134	241.6	115.6	199.1	109.93
87	2.5	0.132	22.50	6093	270.8	123.0	219.3	741.26
87	2.5	0.066	22.50	6093	270.8	123.0	219.3	339.13
87	2.5	0.033	22.50	6093	270.8	123.0	219.3	138.06

TABLE XLVII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR GS3 IRRIGATION SCHEDULING PROCEDURE

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ha	cm	kg/ha	kg/ha-cm	kg/ha-cm	kg/ha-cm	$/ha
84	7.5	0.132	29.38	6343	215.9	168.7	239.6	754.99
84	7.5	0.066	29.38	6343	215.9	168.7	239.6	336.36
84	7.5	0.033	29.38	6343	215.9	168.7	239.6	127.05
85	7.5	0.132	22.50	6181	274.7	154.3	243.8	752.92
85	7.5	0.066	22.50	6181	274.7	154.3	243.8	344.96
85	7.5	0.033	22.50	6181	274.7	154.3	243.8	140.98
86	7.5	0.132	22.50	5134	228.2	115.4	198.4	614.66
86	7.5	0.066	22.50	5134	228.2	115.4	198.4	275.83
86	7.5	0.033	22.50	5134	228.2	115.4	198.4	106.41
87	7.5	0.132	22.50	5715	254.0	116.1	207.8	691.35
87	7.5	0.066	22.50	5715	254.0	116.1	207.8	314.17
87	7.5	0.033	22.50	5715	254.0	116.1	207.8	125.59
84	2.5	0.132	27.50	6332	230.3	169.0	240.3	758.82
84	2.5	0.066	27.50	6332	230.3	169.0	240.3	340.91
84	2.5	0.033	27.50	6332	230.3	169.0	240.3	131.95
85	2.5	0.132	20.00	6194	309.7	155.0	245.2	761.59
85	2.5	0.066	20.00	6194	309.7	155.0	245.2	352.80
85	2.5	0.033	20.00	6194	309.7	155.0	245.2	148.40
86	2.5	0.132	21.25	4982	234.4	112.2	193.1	598.09
86	2.5	0.066	21.25	4982	234.4	112.2	193.1	269.29
86	2.5	0.033	21.25	4982	234.4	112.2	193.1	104.90
87	2.5	0.132	19.38	5726	295.5	118.4	215.2	701.62
87	2.5	0.066	19.38	5726	295.5	118.4	215.2	323.68
87	2.5	0.033	19.38	5726	295.5	118.4	215.2	134.71

TABLE XLVIII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR GS13 IRRIGATION SCHEDULING PROCEDURE

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	29.38	6343	215.9	168.9	239.9	754.96
84	7.5	0.066	29.38	6343	215.9	168.9	239.9	336.35
84	7.5	0.033	29.38	6343	215.9	168.9	239.9	127.04
85	7.5	0.132	22.50	6181	274.7	154.3	243.8	752.92
85	7.5	0.066	22.50	6181	274.7	154.3	243.8	344.96
85	7.5	0.033	22.50	6181	274.7	154.3	243.8	140.98
86	7.5	0.132	22.50	5132	228.1	115.5	198.6	614.41
86	7.5	0.066	22.50	5132	228.1	115.5	198.6	275.70
86	7.5	0.033	22.50	5132	228.1	115.5	198.6	106.35
87	7.5	0.132	22.50	5715	254.0	116.1	207.8	691.35
87	7.5	0.066	22.50	5715	254.0	116.1	207.8	314.17
87	7.5	0.033	22.50	5715	254.0	116.1	207.8	125.59
84	2.5	0.132	27.50	6347	230.8	169.5	241.3	760.86
84	2.5	0.066	27.50	6347	230.8	169.5	241.3	341.93
84	2.5	0.033	27.50	6347	230.8	169.5	241.3	132.47
85	2.5	0.132	20.00	6194	309.7	155.0	245.2	761.59
85	2.5	0.066	20.00	6194	309.7	155.0	245.2	352.80
85	2.5	0.033	20.00	6194	309.7	155.0	245.2	148.40
86	2.5	0.132	18.13	5108	281.8	115.2	198.5	623.51
86	2.5	0.066	18.13	5108	281.8	115.2	198.5	286.37
86	2.5	0.033	18.13	5108	281.8	115.2	198.5	117.81
87	2.5	0.132	19.38	5726	295.5	118.4	215.2	701.62
87	2.5	0.066	19.38	5726	295.5	118.4	215.2	323.68
87	2.5	0.033	19.38	5726	295.5	118.4	215.2	134.71

TABLE XLIX

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR DAILY IRRIGATION SCHEDULING PROCEDURE FOR MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	25.00	6117	244.7	167.5	240.9	737.39
84	7.5	0.066	15.63	4730	302.6	146.5	223.4	268.43
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	17.50	5697	325.5	144.4	230.3	703.00
85	7.5	0.066	15.00	5602	373.5	142.4	227.3	327.72
85	7.5	0.033	14.38	5114	355.6	132.2	213.3	128.50
86	7.5	0.132	17.50	4909	280.5	113.5	199.2	599.00
86	7.5	0.066	15.00	4753	316.9	114.3	206.8	271.73
86	7.5	0.033	10.00	4466	446.6	113.4	214.9	119.37
87	7.5	0.132	22.50	5818	258.6	118.5	212.8	704.98
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	8.75	4130	471.9	93.5	184.1	111.77
84	2.5	0.132	20.00	5833	291.6	167.8	246.7	713.95
84	2.5	0.066	15.00	5132	342.1	163.3	252.8	296.70
84	2.5	0.033	12.50	4301	344.1	145.1	232.2	106.92
85	2.5	0.132	15.00	5833	388.9	149.6	240.1	727.98
85	2.5	0.066	12.50	5404	432.3	141.3	229.5	321.63
85	2.5	0.033	10.00	5145	514.5	136.0	222.5	141.80
86	2.5	0.132	15.00	4816	321.1	114.4	205.3	593.72
86	2.5	0.066	10.00	4254	425.4	107.6	203.4	252.80
86	2.5	0.033	7.50	3662	488.3	95.2	184.3	99.84
87	2.5	0.132	15.00	5650	376.7	118.9	219.2	703.80
87	2.5	0.066	10.00	5124	512.4	113.6	219.4	310.19
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE L

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR DAILYCV IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	25.63	6155	240.2	168.3	241.9	740.70
84	7.5	0.066	21.25	5768	271.4	165.7	243.6	321.17
84	7.5	0.033	15.00	4730	315.3	146.5	223.4	114.10
85	7.5	0.132	17.50	5697	325.5	144.4	230.3	703.00
85	7.5	0.066	15.63	5690	364.0	144.3	230.2	331.77
85	7.5	0.033	14.38	5114	355.6	132.2	213.3	128.50
86	7.5	0.132	21.88	4924	225.1	113.7	199.4	588.72
86	7.5	0.066	15.00	4783	318.9	114.0	204.7	273.67
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	5866	260.7	119.4	214.0	711.31
87	7.5	0.066	22.50	5664	251.7	116.9	212.0	310.84
87	7.5	0.033	15.00	4852	323.5	105.9	201.5	118.12
84	2.5	0.132	20.00	5896	294.8	167.8	245.6	722.28
84	2.5	0.066	17.50	5482	313.3	169.2	257.6	312.84
84	2.5	0.033	12.50	4609	368.7	152.0	239.9	117.10
85	2.5	0.132	15.00	5904	393.6	150.8	241.6	737.31
85	2.5	0.066	12.50	5581	446.5	144.8	234.1	333.34
85	2.5	0.033	10.63	5232	492.2	137.9	225.1	142.90
86	2.5	0.132	15.00	4820	321.3	113.9	203.3	594.26
86	2.5	0.066	12.50	4582	366.5	113.1	209.2	267.38
86	2.5	0.033	7.50	3753	500.5	97.2	187.9	102.86
87	2.5	0.132	15.00	5720	381.3	120.1	220.8	713.04
87	2.5	0.066	12.50	5164	413.1	114.3	220.4	305.84
87	2.5	0.033	7.50	4518	602.4	103.2	205.1	128.10

TABLE LI

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR COND IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ha	cm	kg/ha	kg/ha-cm	kg/ha-cm	kg/ha-cm	$/ha
84	7.5	0.132	20.63	5672	274.9	161.8	236.9	690.95
84	7.5	0.066	15.00	4730	315.3	146.5	223.4	270.19
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	15.00	5326	355.1	136.6	219.3	661.03
85	7.5	0.066	13.13	5074	386.4	131.6	212.7	298.11
85	7.5	0.033	10.00	4911	491.1	129.2	210.7	134.07
86	7.5	0.132	15.00	4819	321.3	113.5	202.1	594.10
86	7.5	0.066	11.25	3996	355.2	99.7	186.2	232.27
86	7.5	0.033	7.50	3602	480.3	92.4	176.7	97.86
87	7.5	0.132	15.00	5464	364.3	115.3	213.2	679.25
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	7.50	4197	559.5	95.0	187.2	117.49
84	2.5	0.132	17.50	5662	323.6	168.5	251.8	698.41
84	2.5	0.066	12.50	4947	395.8	159.2	247.8	291.51
84	2.5	0.033	10.00	4098	409.8	139.4	224.3	107.23
85	2.5	0.132	13.13	5609	427.2	145.4	234.9	703.65
85	2.5	0.066	11.25	5270	468.5	138.6	226.1	316.35
85	2.5	0.033	8.75	4907	560.7	131.2	216.2	137.41
86	2.5	0.132	12.50	4572	365.7	111.3	203.4	568.45
86	2.5	0.066	10.00	4237	423.7	107.3	202.8	251.61
86	2.5	0.033	7.50	3629	483.9	94.4	183.1	98.75
87	2.5	0.132	12.50	5440	435.2	117.5	221.6	683.06
87	2.5	0.066	10.00	4859	485.9	109.0	212.6	292.72
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR CONDCV IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	21.25	5742	270.2	161.7	235.5	698.47
84	7.5	0.066	15.00	4730	315.3	146.5	223.4	270.19
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	15.00	5429	361.9	138.8	222.3	674.58
85	7.5	0.066	13.13	5074	386.4	131.6	212.7	298.11
85	7.5	0.033	10.63	4949	465.6	129.8	211.2	133.56
86	7.5	0.132	15.00	4818	321.2	112.3	198.3	593.99
86	7.5	0.066	14.38	4060	282.3	100.9	187.8	227.69
86	7.5	0.033	7.50	3602	480.3	92.4	176.7	97.86
87	7.5	0.132	15.00	5593	372.9	117.3	215.6	696.26
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	7.50	4124	549.9	93.4	184.0	115.10
84	2.5	0.132	17.50	5569	318.2	162.5	240.5	686.05
84	2.5	0.066	15.00	5105	340.4	162.8	252.4	294.95
84	2.5	0.033	10.00	4142	414.2	140.5	225.7	108.69
85	2.5	0.132	13.75	5707	415.0	147.4	237.6	714.81
85	2.5	0.066	11.25	5318	472.7	139.7	227.5	319.50
85	2.5	0.033	10.00	5029	502.9	133.5	219.0	137.95
86	2.5	0.132	12.50	4590	367.2	111.1	202.3	570.85
86	2.5	0.066	10.00	4237	423.7	107.3	202.8	251.61
86	2.5	0.033	7.50	3629	483.9	94.4	183.1	98.75
87	2.5	0.132	12.50	5512	441.0	118.4	222.2	692.62
87	2.5	0.066	10.00	5124	512.4	113.6	219.4	310.19
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LIII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR FCST IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	25.63	6155	240.2	168.3	241.9	740.70
84	7.5	0.066	22.50	5896	262.0	163.0	235.5	326.13
84	7.5	0.033	15.00	4632	308.8	144.8	222.0	110.87
85	7.5	0.132	17.50	5697	325.5	144.4	230.3	703.00
85	7.5	0.066	15.63	5690	364.0	144.3	230.2	331.77
85	7.5	0.033	13.75	5569	405.0	144.2	232.8	145.27
86	7.5	0.132	21.88	4927	225.2	113.1	197.5	589.05
86	7.5	0.066	15.00	4753	316.9	114.3	206.8	271.73
86	7.5	0.033	14.38	4060	282.3	100.9	187.4	93.71
87	7.5	0.132	22.50	5809	258.2	118.3	212.2	703.85
87	7.5	0.066	15.63	5643	361.0	116.0	209.8	328.65
87	7.5	0.033	15.00	4410	294.0	98.3	190.6	103.54
84	2.5	0.132	20.00	5825	291.3	167.2	245.6	712.94
84	2.5	0.066	15.00	5132	342.1	163.3	252.8	296.70
84	2.5	0.033	12.50	4590	367.2	151.6	239.6	116.46
85	2.5	0.132	15.00	5842	389.5	149.6	240.0	729.13
85	2.5	0.066	12.50	5316	425.3	139.0	225.8	315.88
85	2.5	0.033	10.63	5207	489.8	137.3	224.2	142.06
86	2.5	0.132	15.00	4806	320.4	114.0	204.2	592.33
86	2.5	0.066	10.00	4237	423.7	107.3	202.8	251.61
86	2.5	0.033	8.13	4209	517.7	107.3	204.3	116.12
87	2.5	0.132	15.00	5600	373.4	117.0	214.4	697.24
87	2.5	0.066	12.50	5332	426.5	115.6	218.8	316.90
87	2.5	0.033	7.50	4518	602.4	103.2	205.1	128.10

TABLE LIV

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR COMFCST IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	20.63	5667	274.7	160.8	235.0	690.24
84	7.5	0.066	15.00	4730	315.3	146.5	223.4	270.19
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	15.00	5214	347.6	134.1	215.8	646.25
85	7.5	0.066	13.13	5074	386.4	131.6	212.7	298.11
85	7.5	0.033	10.00	4911	491.1	129.2	210.7	134.07
86	7.5	0.132	15.00	4819	321.3	113.2	202.1	594.10
86	7.5	0.066	10.00	3959	395.9	99.0	185.3	233.28
86	7.5	0.033	7.50	3602	480.3	92.4	176.7	97.86
87	7.5	0.132	15.00	5593	372.9	117.3	215.6	696.26
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	7.50	4124	549.9	93.4	184.0	115.10
84	2.5	0.132	17.50	5504	314.5	165.5	248.7	677.56
84	2.5	0.066	12.50	4948	395.8	159.2	247.9	291.57
84	2.5	0.033	10.00	4142	414.2	140.5	225.7	108.69
85	2.5	0.132	12.50	5524	441.9	143.7	232.7	694.13
85	2.5	0.066	11.25	5293	470.5	139.1	226.8	317.81
85	2.5	0.033	8.75	4907	560.7	131.2	216.2	137.41
86	2.5	0.132	12.50	4544	363.5	110.7	202.5	564.79
86	2.5	0.066	10.00	4213	421.3	106.7	201.9	250.08
86	2.5	0.033	6.88	3575	519.6	93.2	181.0	98.70
87	2.5	0.132	12.50	5512	441.0	118.4	222.2	692.62
87	2.5	0.066	10.00	4859	485.9	109.0	212.6	292.72
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LV

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR CONDFCST IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	20.63	5672	274.9	161.8	236.9	690.95
84	7.5	0.066	15.00	4730	315.3	146.5	223.4	270.19
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	15.00	5326	355.1	136.6	219.3	661.03
85	7.5	0.066	13.13	5074	386.4	131.6	212.7	298.11
85	7.5	0.033	9.38	4877	519.9	128.7	210.3	134.66
86	7.5	0.132	15.00	4797	319.8	113.9	204.0	591.20
86	7.5	0.066	11.25	3996	355.2	99.7	186.2	232.27
86	7.5	0.033	7.50	3602	480.3	92.4	176.7	97.86
87	7.5	0.132	15.00	5464	364.3	115.3	213.2	679.25
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	7.50	4124	549.9	93.4	184.0	115.10
84	2.5	0.132	17.50	5585	319.2	166.8	249.8	688.28
84	2.5	0.066	12.50	4948	395.8	159.2	247.9	291.57
84	2.5	0.033	10.00	4098	409.8	139.4	224.3	107.23
85	2.5	0.132	12.50	5594	447.5	145.1	234.5	703.36
85	2.5	0.066	10.63	5262	495.0	138.5	226.0	317.53
85	2.5	0.033	8.75	4864	555.9	130.3	214.9	136.01
86	2.5	0.132	12.50	4547	363.8	111.2	204.0	565.19
86	2.5	0.066	10.00	4181	418.1	106.1	201.0	247.94
86	2.5	0.033	7.50	3531	470.8	92.3	179.6	95.53
87	2.5	0.132	12.50	5332	426.5	115.6	218.8	668.81
87	2.5	0.066	10.00	4859	485.9	109.0	212.6	292.72
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LVI

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR COMFCV IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	21.88	5806	265.3	162.5	236.0	705.07
84	7.5	0.066	15.00	4730	315.3	146.5	223.4	270.19
84	7.5	0.033	13.75	4246	308.8	137.2	214.3	101.63
85	7.5	0.132	15.00	5429	361.9	138.8	222.3	674.58
85	7.5	0.066	13.75	5096	370.6	131.9	213.1	297.86
85	7.5	0.033	10.63	4949	465.6	129.8	211.2	133.56
86	7.5	0.132	15.00	4821	321.4	112.0	197.3	594.34
86	7.5	0.066	14.38	4060	282.3	100.9	187.8	227.69
86	7.5	0.033	7.50	3602	480.3	92.4	176.7	97.86
87	7.5	0.132	15.00	5593	372.9	117.3	215.6	696.26
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	7.50	4124	549.9	93.4	184.0	115.10
84	2.5	0.132	17.50	5761	329.2	167.6	247.8	711.49
84	2.5	0.066	15.00	5105	340.4	162.8	252.4	294.95
84	2.5	0.033	10.00	4375	437.5	146.5	233.5	116.39
85	2.5	0.132	13.75	5707	415.0	147.4	237.6	714.81
85	2.5	0.066	11.25	5318	472.7	139.7	227.5	319.50
85	2.5	0.033	9.38	4932	525.8	131.6	216.6	136.49
86	2.5	0.132	14.38	4752	330.5	113.6	204.6	587.00
86	2.5	0.066	10.00	4237	423.7	107.3	202.8	251.61
86	2.5	0.033	7.50	3587	478.2	93.4	181.3	97.36
87	2.5	0.132	12.50	5512	441.0	118.4	222.2	692.62
87	2.5	0.066	10.00	5124	512.4	113.6	219.4	310.19
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LVII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR CONDFCV IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	21.25	5742	270.2	161.7	235.5	698.47
84	7.5	0.066	15.00	4730	315.3	146.5	223.4	270.17
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	15.00	5429	361.9	138.8	222.3	674.58
85	7.5	0.066	13.13	5074	386.4	131.6	212.7	298.11
85	7.5	0.033	10.63	4949	465.6	129.8	211.2	133.56
86	7.5	0.132	15.00	4818	321.2	112.3	198.3	593.99
86	7.5	0.066	14.38	4060	282.3	100.9	187.8	227.69
86	7.5	0.033	7.50	3602	480.3	92.4	176.7	97.86
87	7.5	0.132	15.00	5593	372.9	117.3	215.6	696.26
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	7.50	4124	549.9	93.4	184.0	115.10
84	2.5	0.132	17.50	5772	329.9	168.4	249.3	712.95
84	2.5	0.066	15.00	5105	340.4	162.8	252.4	294.95
84	2.5	0.033	10.00	4142	414.2	140.5	225.7	108.69
85	2.5	0.132	13.13	5703	434.3	147.3	237.6	716.02
85	2.5	0.066	11.25	5318	472.7	139.7	227.5	319.50
85	2.5	0.033	9.38	4962	529.0	132.2	217.4	137.47
86	2.5	0.132	12.50	4590	367.2	111.1	202.3	570.85
86	2.5	0.066	10.00	4237	423.7	107.3	202.8	251.61
86	2.5	0.033	7.50	3629	483.9	94.4	183.1	98.75
87	2.5	0.132	12.50	5504	440.3	118.3	221.9	691.56
87	2.5	0.066	10.00	5124	512.4	113.6	219.4	310.19
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LVIII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR PERFECT IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	25.63	6150	240.0	168.4	242.2	740.08
84	7.5	0.066	22.50	5914	262.8	163.6	236.5	327.31
84	7.5	0.033	15.00	4651	310.1	145.4	224.1	111.50
85	7.5	0.132	17.50	5697	325.5	144.4	230.3	703.00
85	7.5	0.066	15.63	5690	364.0	144.3	230.2	331.77
85	7.5	0.033	15.00	5215	347.6	134.2	215.8	130.08
86	7.5	0.132	22.50	5014	222.8	114.8	200.0	598.81
86	7.5	0.066	15.00	4697	319.8	113.9	203.5	268.00
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	5861	260.5	119.2	213.6	710.60
87	7.5	0.066	22.50	5782	257.0	118.4	213.3	318.60
87	7.5	0.033	15.00	4852	323.5	105.9	201.5	118.12
84	2.5	0.132	20.00	5965	298.3	169.2	247.1	731.44
84	2.5	0.066	17.50	5358	306.2	164.4	249.7	304.66
84	2.5	0.033	12.50	4609	368.7	152.0	239.9	117.10
85	2.5	0.132	15.00	5934	395.6	151.4	242.3	741.24
85	2.5	0.066	13.13	5675	432.3	146.8	236.8	337.82
85	2.5	0.033	11.25	5271	468.5	138.6	226.1	142.44
86	2.5	0.132	15.00	4814	321.0	113.8	203.4	593.49
86	2.5	0.066	12.50	4562	364.9	111.5	204.5	266.07
86	2.5	0.033	10.00	4217	421.7	107.3	203.6	111.16
87	2.5	0.132	15.00	5754	383.6	120.2	220.3	717.56
87	2.5	0.066	12.50	5332	426.5	115.6	218.8	316.90
87	2.5	0.033	10.00	4859	485.9	109.0	212.6	132.36

TABLE LIX

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR DAILY IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ha	cm	kg/ha	kg/ha-cm	kg/ha-cm	kg/ha-cm	$/ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	16.25	4732	291.2	146.5	223.5	266.82
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	20.00	6124	306.2	153.5	243.0	752.36
85	7.5	0.066	18.13	5699	314.4	144.4	230.3	325.40
85	7.5	0.033	14.38	5114	355.6	132.2	213.3	128.50
86	7.5	0.132	22.50	4984	221.5	114.8	201.0	594.94
86	7.5	0.066	15.00	4791	319.4	114.5	206.3	274.18
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	6004	266.9	121.5	217.1	729.55
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	11.88	4171	351.1	94.2	185.0	104.36
84	2.5	0.132	22.50	5966	265.1	168.5	245.7	724.47
84	2.5	0.066	15.00	5132	342.1	163.3	252.8	296.70
84	2.5	0.033	12.50	4224	337.9	142.5	228.1	104.39
85	2.5	0.132	15.63	5939	380.0	151.5	242.5	740.25
85	2.5	0.066	13.75	5707	415.0	147.4	237.6	338.15
85	2.5	0.033	11.25	5293	470.5	139.1	226.8	143.16
86	2.5	0.132	15.00	4870	324.7	114.7	204.2	600.86
86	2.5	0.066	11.88	4388	369.4	110.6	208.2	256.38
86	2.5	0.033	7.50	3753	500.5	97.2	187.8	102.86
87	2.5	0.132	17.50	5766	329.5	120.3	220.2	712.14
87	2.5	0.066	12.50	5164	413.1	114.3	220.4	305.84
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LX

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR DAILYCV IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	26.25	6152	234.4	168.6	242.5	332.55
84	7.5	0.033	16.25	4732	291.2	146.5	223.5	110.66
85	7.5	0.132	20.00	6140	307.0	153.7	243.3	754.45
85	7.5	0.066	18.13	5700	314.4	144.4	230.3	325.42
85	7.5	0.033	16.25	5532	340.4	140.9	225.4	137.05
86	7.5	0.132	22.50	5073	225.4	114.9	198.6	606.58
86	7.5	0.066	15.00	4791	319.4	114.5	206.3	274.18
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	6020	267.6	121.7	217.3	731.68
87	7.5	0.066	22.50	5675	252.2	117.0	212.1	311.56
87	7.5	0.033	15.00	4852	323.5	105.9	201.5	118.12
84	2.5	0.132	22.50	6036	268.3	169.1	245.6	733.78
84	2.5	0.066	17.50	5529	316.0	166.8	251.1	315.93
84	2.5	0.033	12.50	4609	368.7	152.0	239.9	117.10
85	2.5	0.132	16.25	5948	366.0	151.7	242.7	739.68
85	2.5	0.066	14.38	5805	403.7	149.2	240.0	342.88
85	2.5	0.033	11.88	5331	448.7	139.8	227.7	142.65
86	2.5	0.132	16.88	4962	294.0	116.1	205.6	607.75
86	2.5	0.066	12.50	4571	365.7	111.7	204.7	266.70
86	2.5	0.033	10.00	4217	421.7	107.1	203.3	111.17
87	2.5	0.132	17.50	5860	334.8	121.3	220.5	724.46
87	2.5	0.066	15.00	5525	368.4	118.6	222.4	322.68
87	2.5	0.033	10.00	4859	485.9	109.0	212.6	132.36

TABLE LXI

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR COND IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	21.25	5004	235.5	145.8	215.7	270.77
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	20.00	6090	304.5	153.2	243.1	747.86
85	7.5	0.066	18.13	5700	314.4	144.4	230.3	325.42
85	7.5	0.033	14.38	5116	355.7	132.2	213.3	128.55
86	7.5	0.132	22.50	4984	221.5	114.8	201.0	594.94
86	7.5	0.066	18.13	4758	262.4	114.3	206.9	263.24
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	5977	265.6	121.0	216.2	725.90
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	8.75	4130	471.9	93.5	184.1	111.77
84	2.5	0.132	22.50	6028	267.9	169.8	247.3	732.71
84	2.5	0.066	17.50	5557	317.6	169.0	255.3	317.79
84	2.5	0.033	12.50	4206	336.5	142.0	227.6	103.79
85	2.5	0.132	16.25	5954	366.4	151.8	242.9	740.49
85	2.5	0.066	13.75	5638	410.0	145.9	235.7	333.58
85	2.5	0.033	11.25	5316	472.6	139.6	227.5	143.94
86	2.5	0.132	17.50	4970	284.0	116.2	205.6	607.01
86	2.5	0.066	12.50	4595	367.6	112.8	207.8	268.30
86	2.5	0.033	10.00	4237	423.7	107.3	202.8	111.80
87	2.5	0.132	17.50	5818	332.4	121.2	221.5	718.93
87	2.5	0.066	12.50	5158	412.6	114.2	220.2	305.42
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LXII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR CONDCV IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	22.50	5867	260.8	167.7	246.0	324.23
84	7.5	0.033	16.25	4732	291.2	146.5	223.5	110.66
85	7.5	0.132	20.00	6106	305.3	153.2	242.9	749.96
85	7.5	0.066	18.13	5700	314.4	144.4	230.3	325.42
85	7.5	0.033	16.88	5694	337.3	144.4	230.3	140.65
86	7.5	0.132	22.50	5094	226.4	115.1	198.5	609.47
86	7.5	0.066	18.75	4803	256.2	114.3	205.0	264.52
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	5965	265.1	120.7	215.6	724.35
87	7.5	0.066	22.50	5977	265.6	121.0	216.2	331.45
87	7.5	0.033	15.00	4850	323.3	105.8	223.1	118.05
84	2.5	0.132	22.50	6082	270.3	170.5	247.7	739.81
84	2.5	0.066	17.50	5540	316.6	167.5	252.4	316.66
84	2.5	0.033	15.00	4929	328.6	158.6	247.1	120.65
85	2.5	0.132	16.25	5954	366.4	151.8	242.9	740.49
85	2.5	0.066	14.38	5817	404.5	149.3	239.9	343.63
85	2.5	0.033	11.88	5352	450.5	140.3	228.3	143.35
86	2.5	0.132	17.50	4971	284.1	116.1	205.4	607.18
86	2.5	0.066	12.50	4595	367.6	112.8	207.8	268.30
86	2.5	0.033	10.00	4254	425.4	107.6	203.4	112.40
87	2.5	0.132	17.50	5864	335.1	121.8	222.2	725.07
87	2.5	0.066	15.00	5525	368.4	118.7	222.4	322.68
87	2.5	0.033	10.00	5124	512.4	113.6	219.4	141.10

TABLE LXIII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR FCST IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	26.25	6150	234.3	168.5	242.4	332.38
84	7.5	0.033	15.63	4632	296.4	144.8	222.0	109.10
85	7.5	0.132	20.00	6067	303.3	152.0	240.7	744.80
85	7.5	0.066	18.13	5700	314.4	144.4	230.3	325.42
85	7.5	0.033	16.25	5692	350.3	144.4	230.2	142.33
86	7.5	0.132	22.50	5062	225.0	114.5	197.6	605.12
86	7.5	0.066	15.00	4753	316.9	114.3	206.8	271.73
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	6004	266.9	121.5	217.1	729.55
87	7.5	0.066	22.50	5782	257.0	118.4	213.3	318.60
87	7.5	0.033	15.00	4410	294.0	98.3	190.6	103.54
84	2.5	0.132	22.50	6034	268.2	170.5	246.7	733.45
84	2.5	0.066	17.50	5529	316.0	166.8	251.1	315.93
84	2.5	0.033	15.00	4986	332.4	160.5	250.0	122.54
85	2.5	0.132	16.25	5949	366.1	151.7	242.7	739.71
85	2.5	0.066	15.00	5800	386.7	149.1	239.7	340.83
85	2.5	0.033	12.50	5366	429.3	140.5	228.4	142.07
86	2.5	0.132	15.63	4952	316.8	115.9	206.3	609.90
86	2.5	0.066	12.50	4572	365.7	112.3	206.9	266.72
86	2.5	0.033	10.00	4213	421.3	106.7	201.9	111.04
87	2.5	0.132	17.50	5808	331.9	120.4	219.1	717.63
87	2.5	0.066	13.13	5492	418.3	117.7	220.4	325.71
87	2.5	0.033	8.13	4519	555.8	103.2	203.3	126.35

TABLE LXIV

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR COMFCST IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	16.25	5078	312.5	157.2	239.9	289.63
84	7.5	0.033	14.38	4382	304.7	140.0	217.4	104.34
85	7.5	0.132	20.00	5989	299.4	150.1	237.7	734.54
85	7.5	0.066	18.13	5700	314.4	144.4	230.3	325.42
85	7.5	0.033	14.38	5114	355.6	132.2	213.3	128.50
86	7.5	0.132	22.50	4984	221.5	114.8	201.0	594.94
86	7.5	0.066	15.00	4753	316.9	114.3	206.8	271.73
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	6004	266.9	121.5	217.1	729.55
87	7.5	0.066	15.00	4746	316.4	97.9	177.4	271.23
87	7.5	0.033	14.38	4388	305.2	97.9	190.1	104.55
84	2.5	0.132	22.50	6036	268.3	169.9	247.3	733.78
84	2.5	0.066	15.00	5132	342.1	163.3	252.8	296.70
84	2.5	0.033	12.50	4224	337.9	142.5	228.1	104.39
85	2.5	0.132	16.25	5942	365.7	151.6	242.5	738.90
85	2.5	0.066	13.75	5694	414.1	147.1	237.2	337.28
85	2.5	0.033	11.88	5331	448.7	139.8	227.6	142.65
86	2.5	0.132	15.00	4828	321.9	113.9	203.1	595.34
86	2.5	0.066	12.50	4582	366.5	113.1	209.2	267.38
86	2.5	0.033	9.38	4105	437.6	105.0	200.4	109.20
87	2.5	0.132	15.63	5744	367.5	119.5	218.1	714.43
87	2.5	0.066	12.50	5526	442.1	119.0	199.4	329.74
87	2.5	0.033	8.13	4518	555.7	103.2	205.1	126.34

TABLE LXV

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR CONDFCST IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	16.25	4732	291.2	146.5	223.5	266.81
84	7.5	0.033	13.13	4040	307.7	132.2	207.9	96.57
85	7.5	0.132	20.00	6064	303.2	152.0	240.6	744.46
85	7.5	0.066	18.13	5700	314.4	144.4	230.3	325.42
85	7.5	0.033	14.38	5114	355.6	132.2	213.3	128.50
86	7.5	0.132	22.50	4984	221.5	114.8	201.0	594.94
86	7.5	0.066	15.00	4791	319.4	114.5	206.3	274.18
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	6004	266.9	121.5	217.1	729.55
87	7.5	0.066	15.00	4852	323.5	105.9	201.5	278.24
87	7.5	0.033	11.88	4171	351.1	94.2	185.0	104.36
84	2.5	0.132	22.50	5966	265.1	168.5	245.7	724.47
84	2.5	0.066	15.00	5132	342.1	163.3	252.8	296.70
84	2.5	0.033	12.50	4224	337.9	142.5	228.1	104.39
85	2.5	0.132	15.63	5944	380.3	151.6	242.7	740.82
85	2.5	0.066	13.75	5707	415.0	147.4	237.6	338.15
85	2.5	0.033	11.25	5293	470.5	139.1	226.8	143.16
86	2.5	0.132	15.00	4870	324.7	114.7	204.2	600.86
86	2.5	0.066	11.88	4395	370.0	110.7	208.5	256.83
86	2.5	0.033	7.50	3753	500.5	97.2	187.8	102.86
87	2.5	0.132	15.00	5751	383.4	120.0	219.7	717.11
87	2.5	0.066	10.63	5124	482.0	113.6	219.4	308.43
87	2.5	0.033	7.50	4192	559.0	97.3	196.2	117.35

TABLE LXVI

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR COMFCV IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	26.25	6152	234.4	168.6	242.5	332.55
84	7.5	0.033	16.25	4732	291.2	146.5	223.5	110.66
85	7.5	0.132	20.00	6140	307.0	153.7	243.3	754.45
85	7.5	0.066	18.13	5700	314.4	144.4	230.3	325.42
85	7.5	0.033	16.25	5604	344.8	142.4	227.3	139.42
86	7.5	0.132	22.50	5073	225.4	114.9	198.6	606.58
86	7.5	0.066	16.88	4821	285.6	114.7	205.9	270.93
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	6020	267.6	121.7	217.3	731.68
87	7.5	0.066	22.50	5721	254.3	117.5	212.4	314.57
87	7.5	0.033	15.11	4852	321.1	105.9	201.5	117.81
84	2.5	0.132	22.50	6085	270.4	169.8	246.4	740.21
84	2.5	0.066	17.50	5494	313.9	165.0	247.8	313.59
84	2.5	0.033	15.00	4972	331.4	159.6	248.3	122.06
85	2.5	0.132	16.25	5948	366.0	151.7	242.7	739.68
85	2.5	0.066	15.00	5813	387.5	149.2	239.6	341.63
85	2.5	0.033	12.50	5344	427.6	140.0	227.8	141.37
86	2.5	0.132	16.88	4963	294.0	116.0	205.4	607.90
86	2.5	0.066	12.50	4616	369.3	111.9	167.0	269.65
86	2.5	0.033	10.00	4217	421.7	107.1	203.3	111.17
87	2.5	0.132	17.50	5868	335.3	121.0	219.4	725.57
87	2.5	0.066	12.50	5504	440.3	118.3	221.9	328.28
87	2.5	0.033	10.00	4859	485.9	109.0	212.6	132.36

TABLE LXVII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR CONDFCV IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.25	6188	235.7	168.9	242.6	743.31
84	7.5	0.066	26.25	6152	234.4	168.6	242.5	332.55
84	7.5	0.033	16.25	4732	291.2	146.5	223.5	110.66
85	7.5	0.132	20.00	6140	307.0	153.7	243.3	754.45
85	7.5	0.066	18.13	5700	314.4	144.4	230.3	325.42
85	7.5	0.033	16.25	5532	340.4	140.9	225.4	137.05
86	7.5	0.132	22.50	5073	225.4	114.9	198.6	606.58
86	7.5	0.066	15.00	4791	319.4	114.5	205.4	274.18
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	6020	267.6	121.7	217.3	731.68
87	7.5	0.066	22.50	5675	252.2	117.0	211.9	311.56
87	7.5	0.033	15.00	4852	323.5	105.9	201.5	118.12
84	2.5	0.132	22.50	6035	268.2	169.1	245.5	733.63
84	2.5	0.066	17.50	5529	316.0	166.8	251.1	315.93
84	2.5	0.033	12.50	4609	368.7	152.0	239.9	117.10
85	2.5	0.132	16.25	5948	366.0	151.7	242.7	739.68
85	2.5	0.066	14.38	5805	403.7	149.2	240.0	342.88
85	2.5	0.033	11.88	5331	448.7	139.8	227.6	142.65
86	2.5	0.132	16.88	4962	294.0	116.1	205.6	607.75
86	2.5	0.066	12.50	4522	361.8	110.3	202.0	263.47
86	2.5	0.033	10.00	4217	421.7	107.1	203.3	111.17
87	2.5	0.132	17.50	5860	334.8	121.3	220.5	724.46
87	2.5	0.066	15.00	5525	368.4	118.6	222.4	322.68
87	2.5	0.033	10.00	4859	485.9	109.0	212.6	132.36

TABLE LXVIII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR PERFECT IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ha	cm	kg/ha	kg/ha-cm	kg/ha-cm	kg/ha-cm	$/ha
84	7.5	0.132	26.25	6120	233.1	167.6	240.9	734.31
84	7.5	0.066	26.25	6118	233.1	167.9	241.7	330.28
84	7.5	0.033	15.00	4579	305.2	143.2	220.6	109.10
85	7.5	0.132	20.00	6140	307.0	153.7	243.2	754.47
85	7.5	0.066	18.13	5700	314.4	143.8	230.3	325.42
85	7.5	0.033	16.25	5692	350.3	144.4	230.2	142.33
86	7.5	0.132	22.50	5073	225.4	114.9	198.6	606.58
86	7.5	0.066	17.50	4846	276.9	114.8	205.3	270.84
86	7.5	0.033	14.38	4060	282.3	100.9	187.8	93.71
87	7.5	0.132	22.50	6020	267.6	121.7	217.3	731.68
87	7.5	0.066	22.50	5782	257.0	118.4	213.3	318.60
87	7.5	0.033	15.00	4852	323.5	105.9	201.5	118.12
84	2.5	0.132	22.50	5970	265.3	167.6	243.7	725.08
84	2.5	0.066	20.00	5688	284.4	168.0	250.4	319.43
84	2.5	0.033	15.00	4814	320.9	156.4	244.9	116.86
85	2.5	0.132	16.25	5954	366.4	151.8	242.9	740.49
85	2.5	0.066	15.00	5766	384.4	148.0	237.7	338.56
85	2.5	0.033	12.50	5366	429.3	140.5	228.4	142.07
86	2.5	0.132	16.88	4961	293.9	116.0	205.3	607.59
86	2.5	0.066	12.50	4556	364.4	110.8	202.3	265.66
86	2.5	0.033	10.00	4222	422.2	107.0	202.5	111.32
87	2.5	0.132	17.50	5867	335.3	121.0	219.1	725.50
87	2.5	0.066	15.00	5506	367.1	117.9	220.6	321.38
87	2.5	0.033	10.00	4859	485.9	109.0	212.6	132.36

TABLE LXIX

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR GSO IRRIGATION SCHEDULING PROCEDURE AND DOUBLED RAINFALL VALUES

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.68	6370	238.7	151.4	252.3	766.08
84	7.5	0.066	26.68	6370	238.7	151.4	252.3	345.69
84	7.5	0.033	26.68	6370	238.7	151.4	252.3	135.49
85	7.5	0.132	15.00	6209	413.9	145.2	252.9	777.53
85	7.5	0.066	15.00	6209	413.9	145.2	252.9	367.76
85	7.5	0.033	15.00	6209	413.9	145.2	252.9	162.88
86	7.5	0.132	7.50	5154	687.2	109.1	202.6	659.37
86	7.5	0.066	7.50	5154	687.2	109.1	202.6	319.18
86	7.5	0.033	7.50	5154	687.2	109.1	202.6	149.09
87	7.5	0.132	15.00	6088	405.8	116.8	222.5	761.57
87	7.5	0.066	15.00	6088	405.8	116.8	222.5	359.79
87	7.5	0.033	15.00	6088	405.8	121.5	222.5	158.89
84	2.5	0.132	25.00	6378	255.1	151.8	250.4	771.94
84	2.5	0.066	25.00	6378	255.1	151.8	250.4	350.97
84	2.5	0.033	25.00	6378	255.1	151.8	250.4	140.49
85	2.5	0.132	15.00	6212	414.2	145.4	253.4	778.05
85	2.5	0.066	15.00	6212	414.2	145.4	253.4	368.02
85	2.5	0.033	15.00	6212	414.2	145.4	253.4	163.01
86	2.5	0.132	5.00	5142	1028.4	108.9	202.3	664.78
86	2.5	0.066	5.00	5142	1028.4	108.9	202.3	325.39
86	2.5	0.033	5.00	5142	1028.4	108.9	202.3	155.69
87	2.5	0.132	12.50	6096	487.7	117.1	223.1	769.72
87	2.5	0.066	12.50	6096	487.7	117.1	223.1	367.36
87	2.5	0.033	12.50	6096	487.7	117.1	223.1	166.18

TABLE LXX

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR GS1 IRRIGATION SCHEDULING PROCEDURE AND DOUBLED RAINFALL VALUES

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.88	6368	236.9	151.4	249.7	765.32
84	7.5	0.066	26.88	6368	236.9	151.4	249.7	345.03
84	7.5	0.033	26.88	6368	236.9	151.4	249.7	134.88
85	7.5	0.132	15.00	6209	413.9	145.2	252.9	777.53
85	7.5	0.066	15.00	6209	413.9	145.2	252.9	367.76
85	7.5	0.033	15.00	6209	413.9	145.2	252.9	162.88
86	7.5	0.132	7.50	5154	687.2	109.1	202.6	659.37
86	7.5	0.066	7.50	5154	687.2	109.1	202.6	319.18
86	7.5	0.033	7.50	5154	687.2	109.1	202.6	149.09
87	7.5	0.132	15.00	6088	405.8	116.8	222.5	761.57
87	7.5	0.066	15.00	6088	405.8	116.8	222.5	359.79
87	7.5	0.033	15.00	6088	405.8	121.5	222.5	158.89
84	2.5	0.132	25.00	6378	255.1	151.9	250.5	771.86
84	2.5	0.066	25.00	6378	255.1	151.9	250.5	350.93
84	2.5	0.033	25.00	6378	255.1	151.9	250.5	140.46
85	2.5	0.132	15.00	6212	414.2	145.4	253.4	778.05
85	2.5	0.066	15.00	6212	414.2	145.4	253.4	368.02
85	2.5	0.033	15.00	6212	414.2	145.4	253.4	163.01
86	2.5	0.132	5.00	5142	1028.4	108.9	202.3	664.78
86	2.5	0.066	5.00	5142	1028.4	108.9	202.3	325.39
86	2.5	0.033	5.00	5142	1028.4	108.9	202.3	155.69
87	2.5	0.132	12.50	6096	487.7	117.1	223.1	769.72
87	2.5	0.066	12.50	6096	487.7	117.1	223.1	367.36
87	2.5	0.033	12.50	6096	487.7	117.1	223.1	166.18

TABLE LXXI

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR GS3 IRRIGATION SCHEDULING PROCEDURE AND DOUBLED RAINFALL VALUES

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ha	cm	kg/ha	kg/ha-cm	kg/ha-cm	kg/ha-cm	$/ha
84	7.5	0.132	26.88	6370	237.0	151.4	249.6	765.52
84	7.5	0.066	26.88	6370	237.0	151.4	249.6	345.13
84	7.5	0.033	26.88	6370	237.0	151.4	249.6	134.93
85	7.5	0.132	15.00	6153	410.2	144.0	251.1	770.19
85	7.5	0.066	15.00	6153	410.2	144.0	251.1	364.10
85	7.5	0.033	15.00	6153	410.2	144.0	251.1	161.05
86	7.5	0.132	7.50	5143	685.8	108.9	202.4	657.94
86	7.5	0.066	7.50	5143	685.8	108.9	202.4	318.47
86	7.5	0.033	7.50	5143	685.8	108.9	202.4	148.74
87	7.5	0.132	15.00	5916	394.4	113.8	217.2	738.88
87	7.5	0.066	15.00	5916	394.4	113.8	217.2	348.44
87	7.5	0.033	15.00	5916	394.4	113.8	217.2	153.22
84	2.5	0.132	25.00	6346	253.8	151.4	250.2	767.69
84	2.5	0.066	25.00	6346	253.8	151.5	250.2	348.84
84	2.5	0.033	25.00	6346	253.8	151.5	250.2	139.42
85	2.5	0.132	15.00	6201	413.4	145.3	253.4	776.58
85	2.5	0.066	15.00	6201	413.4	145.3	253.4	367.29
85	2.5	0.033	15.00	6201	413.4	145.3	253.4	162.64
86	2.5	0.132	5.00	5137	1027.4	108.8	202.2	664.06
86	2.5	0.066	5.00	5137	1027.4	108.8	202.2	325.03
86	2.5	0.033	5.00	5137	1027.4	108.8	202.2	155.51
87	2.5	0.132	10.00	6043	604.3	116.4	222.3	769.68
87	2.5	0.066	10.00	6043	604.3	116.4	222.3	370.84
87	2.5	0.033	10.00	6043	604.3	116.4	222.3	171.42

TABLE LXXII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR GS13 IRRIGATION SCHEDULING PROCEDURE AND DOUBLED RAINFALL VALUES

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	26.88	6368	236.9	151.4	249.7	765.34
84	7.5	0.066	26.88	6368	236.9	151.4	249.7	345.04
84	7.5	0.033	26.88	6368	236.9	151.4	249.7	134.89
85	7.5	0.132	15.00	6153	410.2	144.0	251.1	770.19
85	7.5	0.066	15.00	6153	410.2	144.0	251.1	364.10
85	7.5	0.033	15.00	6153	410.2	144.0	251.1	161.05
86	7.5	0.132	7.50	5141	685.5	108.9	202.3	657.61
86	7.5	0.066	7.50	5141	685.5	108.9	202.3	318.30
86	7.5	0.033	7.50	5141	685.5	108.9	202.3	148.65
87	7.5	0.132	15.00	5916	394.4	113.8	217.2	738.88
87	7.5	0.066	15.00	5916	394.4	113.8	217.2	348.44
87	7.5	0.033	15.00	5916	394.4	113.8	217.2	153.22
84	2.5	0.132	25.00	6346	253.8	151.5	250.4	767.64
84	2.5	0.066	25.00	6346	253.8	151.5	250.4	348.82
84	2.5	0.033	25.00	6346	253.8	151.5	250.4	139.41
85	2.5	0.132	15.00	6201	413.4	145.3	253.4	776.58
85	2.5	0.066	15.00	6201	413.4	145.3	253.4	367.29
85	2.5	0.033	15.00	6201	413.4	145.3	253.4	162.64
86	2.5	0.132	5.00	5137	1027.4	108.8	202.2	664.06
86	2.5	0.066	5.00	5137	1027.4	108.8	202.2	325.03
86	2.5	0.033	5.00	5137	1027.4	108.8	202.2	155.51
87	2.5	0.132	10.00	6043	604.3	116.4	222.3	769.68
87	2.5	0.066	10.00	6043	604.3	116.4	222.3	370.84
87	2.5	0.033	10.00	6043	604.3	116.4	222.3	171.42

TABLE LXXIII

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR PERFECT IRRIGATION SCHEDULING PROCEDURE USING MIDDLE PLANT SOIL WATER PROJECTION AND DOUBLED RAINFALL VALUES

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	22.50	6093	270.8	147.3	245.6	741.26
84	7.5	0.066	20.63	5894	285.7	143.5	240.4	331.24
84	7.5	0.033	14.38	4721	328.3	125.8	224.9	115.54
85	7.5	0.132	13.75	5990	435.7	140.5	245.4	752.24
85	7.5	0.066	11.25	5972	530.9	140.3	245.3	362.66
85	7.5	0.033	8.75	5908	675.2	139.2	242.8	170.46
86	7.5	0.132	1.88	5112	2719.2	108.4	201.5	669.54
86	7.5	0.066	0.00	5109	-----	108.3	201.5	337.19
86	7.5	0.033	0.00	5109	-----	108.3	201.5	168.60
87	7.5	0.132	15.00	5916	394.4	113.8	217.2	738.88
87	7.5	0.066	7.50	5693	759.0	109.9	210.4	354.71
87	7.5	0.033	7.50	5693	759.0	109.9	210.4	166.85
84	2.5	0.132	20.00	6010	300.5	149.4	253.8	737.26
84	2.5	0.066	15.00	5465	364.3	145.1	258.7	318.67
84	2.5	0.033	12.50	4977	398.2	135.3	246.0	129.24
85	2.5	0.132	10.00	6057	605.7	142.6	249.6	771.53
85	2.5	0.066	8.75	5891	673.2	139.4	244.9	364.28
85	2.5	0.033	6.25	5543	886.9	132.7	235.5	165.42
86	2.5	0.132	0.00	5109	-----	108.3	201.5	674.38
86	2.5	0.066	0.00	5109	-----	108.3	201.5	337.19
86	2.5	0.033	0.00	5109	-----	108.3	201.5	168.60
87	2.5	0.132	7.50	5829	777.1	113.0	217.1	748.37
87	2.5	0.066	7.50	5829	777.1	113.0	217.1	363.69
87	2.5	0.033	5.00	5713	1142.5	111.1	214.2	174.52

TABLE LXXIV

1984 THROUGH 1987 RESULTS FOR A GRAIN SORGHUM SIMULATION STUDY FOR PERFECT IRRIGATION SCHEDULING PROCEDURE USING LAST PLANT SOIL WATER PROJECTION AND DOUBLED RAINFALL VALUES

YR	NET IRR	GRAIN PRICE	TOTAL IRR	YIELD	IRR WUE	ET WUE	EP WUE	RETURN
	cm	$/ ha	cm	kg/ ha	kg/ ha-cm	kg/ ha-cm	kg/ ha-cm	$/ ha
84	7.5	0.132	22.50	6240	277.3	150.3	249.9	760.66
84	7.5	0.066	22.50	6119	271.9	148.0	246.8	340.84
84	7.5	0.033	15.00	4958	330.5	130.3	230.5	121.60
85	7.5	0.132	15.00	6097	406.4	142.8	249.0	762.76
85	7.5	0.066	15.00	6019	401.3	141.1	246.3	355.28
85	7.5	0.033	12.50	5983	478.6	140.4	245.4	162.43
86	7.5	0.132	7.50	5132	684.2	108.7	202.0	656.41
86	7.5	0.066	7.50	5133	684.4	108.7	202.1	317.80
86	7.5	0.033	0.00	5109	-----	108.3	201.5	168.60
87	7.5	0.132	15.00	6080	405.3	116.7	222.4	760.56
87	7.5	0.066	15.00	5916	394.4	113.8	217.2	348.44
87	7.5	0.033	7.50	5741	765.4	110.7	211.6	168.44
84	2.5	0.132	20.00	6042	302.1	149.3	252.7	741.49
84	2.5	0.066	15.00	5465	364.3	145.1	258.7	318.67
84	2.5	0.033	12.50	4993	399.5	135.6	246.1	129.78
85	2.5	0.132	11.88	6076	511.4	142.9	250.0	768.74
85	2.5	0.066	10.00	5992	599.2	141.3	247.6	367.50
85	2.5	0.033	7.50	5759	767.9	136.6	240.7	169.04
86	2.5	0.132	0.00	5109	-----	108.3	201.5	674.38
86	2.5	0.066	0.00	5109	-----	108.3	201.5	337.19
86	2.5	0.033	0.00	5109	-----	108.3	201.5	168.60
87	2.5	0.132	7.50	5930	790.7	114.6	219.6	761.81
87	2.5	0.066	7.50	5829	777.1	113.0	217.1	363.69
87	2.5	0.033	5.00	5765	1152.9	111.9	215.4	176.23

VITA

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Candidate for the Degree of

Doctor of Philosophy

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