A NEAR-OPTIMAL DYNAMIC PROGRAMMING MODEL FOR ON-FARM IRRIGATION SCHEDULING OF GRAIN SORGHUM IN THE OKLAHOMA PANHANDLE

By

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CHAPTER I

INTRODUCTION

General Problem

Climatic conditions during the growing season for crops in the Oklahoma Panhandle are characterized by sparse precipitation, high temperatures, and often strong winds. These conditions affect crop growth in terms of high evaporation of water from the soil and transpiration by the plant. The low yields from dryland production in this area have lead to the extensive development of irrigation in the past 35 years. The mean annual rainfall in the Oklahoma Panhandle ranges from 16 inches in Cimarron County to just over 20 inches in Beaver County. In these three counties, irrigated acreage increased from 11,500 acres in 1950 to almost 413,000 acres in 1981 and then declined to a little over 336,000 acres in 1983 (1981 and 1983 Irrigation Survey Oklahoma).

The general farm problem in the Oklahoma Panhandle, as throughout the United States, is a depressed agricultural economy due to rising production costs and falling commodity prices. This problem is compounded even more under irrigated production where natural gas (the primary energy source used for pumping irrigation water in the Oklahoma Panhandle) prices have risen faster than the rate of inflation. Also, commodity prices are lowered by over-production and high transportation costs due to the remote location of the three panhandle counties from the major terminal markets. Recent analysis indicates that agricultural commodity prices have an even larger impact than energy prices on the economic life of the irrigation water supply in the Oklahoma Panhandle (Camp Dresser and McKee, Inc., Black and Veatch, and Arthur D. Little, Inc., 1982).

Throughout irrigated regions, farmers have responded to the cost/price squeeze by adopting improved technology. Many irrigators have converted older high pressure central pivot irrigation systems to the more efficient low pressure systems and low pressure systems with drop tubes. Additional savings may be gained in the future through the recently developed Low Energy Pressure Application (LEPA) sprinkler system. These systems reduce variable pumping costs by reducing pressure required to apply the irrigation water and improving water application efficiency.

Farmers have become more concerned with the timing of irrigations during the growing season in order to increase yields or lower costs through fewer applications. The cost of inputs and expected price of the commodity are also important considerations when irrigations are scheduled.

This study focuses on the feasibility of using a computerized plant growth model to schedule irrigations on grain sorghum in accordance with the needs of the plant. Analysis of the impacts of energy and crop prices on irrigation schedules designed to maximize net returns to irrigators is conducted. In addition, the potential impacts of new low pressure and low energy precision application irrigation systems on profitability under irrigation scheduling is evaluated.

Study Area

The major source of ground water in the Oklahoma Panhandle is the Ogallala Aquifer. As depicted in Figure 1, the Ogallala Aquifer extends from southern South Dakota, throughout a large part of Nebraska, into eastern Wyoming, underlies western Kansas, eastern Colorado, the panhandles of Oklahoma and Texas while continuing into southwestern Texas and the eastern border of New Mexico. The Oklahoma Panhandle lies within the Central Basin of the Ogallala Aquifer. This Central Basin is bounded on the north by the Arkansas River in Kansas and on the south by the Canadian River in Texas.

As acres under irrigation increased during the 1950-80 period, withdrawals of water from the Ogallala aquifer greatly exceeded natural recharge. The water table began to decline, pumping lifts increased, well yields were reduced and irrigation pumping costs rose. During the 1970's, declining water supplies combined with rising energy costs and depressed commodity prices to slow the growth of irrigation. Since 1980, low profitability has resulted in irrigated acres returning to dryland production.

Within the Oklahoma Panhandle, natural gas remains the primary fuel used for pumping ground water as shown in Table I. In 1981, 96 percent of the acres were irrigated by natural gas fueled engines, whereas in 1983, 91 percent were irrigated with natural gas. Both electric and gasoline power engines declined while acreage irrigated with diesel power increased by 5,300 acres between 1981 and 1983.

Before price deregulation, the low price of natural gas made irrigation water a relatively inexpensive production input and helped

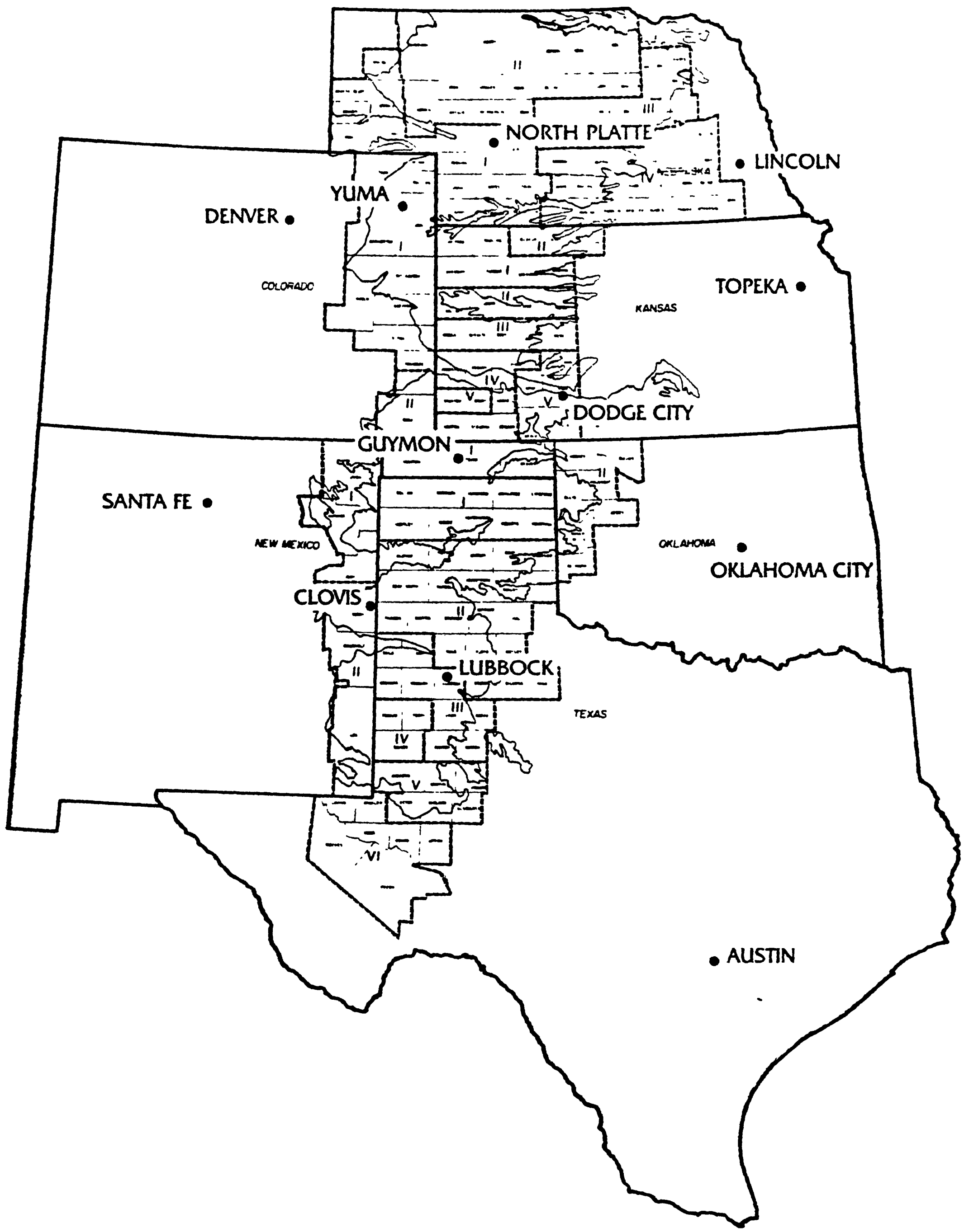

Figure 1. Map of the Ogallala Aquifer in the Central Great Plains

TABLE I.

ENERGY SOURCE FOR PUMPING GROUNDWATER (ACRES)

County	Natural Gas	Diesel	Low Propane	Gasoline	Electric
1983					
Beaver	16,806	5,041	2,689	662	8,402
Texas	165,780	--	--	--	6,000
Cimarron	122,600	500	5,500	800	1,500
TOTAL	305,186	5,541	8,189	1,462	15,902
STATE TOTAL	393,737	32,714	63,811	7,565	127,574
1981					
Beaver	27,830	230	1,340	--	2,200
Texas	275,200	--	--	--	4,080
Cimarron	93,700	--	6,690	--	2,400
TOTAL	396,930	280	8,030	--	8,680
STATE TOTAL	489,894	35,692	83,991	7,130	143,342

Source: 1981 and 1983 Irrigation Survey Oklahoma.

to spur the rapid development of irrigation in this area of the country. However, since that time natural gas prices, for some producers, have increased dramatically as shown in Table II from a study by Nelson, Schatzer and Jobes (1985). Their study indicates that the demand of irrigators for natural gas is highly inelastic at about -3.93 for 1983 price and quantity. For a one percent increase in the price of natural gas, producers will tend to decrease consumption of natural gas by 3.93 percent, which means either irrigating less water per acre or reverting irrigated acres back to dryland.

Irrigated acreage for 1981 and 1983 in the three Oklahoma Panhandle counties, along with the state totals, are shown in Table III. From 1981 to 1983, total irrigated acres in the panhandle declined 18 percent or 76,000 acres. Before 1983, grain sorghum had been the major irrigated crop, on an acreage basis, in the panhandle as well as the entire state. Between the two years, irrigated grain sorghum acreage declined by 65,000 and 75,000 in the panhandle and entire state of Oklahoma, respectively. This large reduction in irrigated grain sorghum acreage indicates the continued need for research on the scheduling of irrigations for that crop under a dynamic price and output environment.

During these same years, irrigated corn fell from 44,600 to only 9,000 acres in the three panhandle counties. Corn requires more irrigation water and cannot withstand the moisture stress that grain sorghum and wheat are capable of enduring. Irrigated wheat acreage in the panhandle increased from 145,655 to 158,483 between 1981 and 1983, but the total states' production dropped by 14,000 acres.

TABLE II

WESTERN GAS INTERSTATE NATURAL GAS SOLD TO IRRIGATORS IN THE OKLAHOMA AND TEXAS PANHANDLES, 1974-1983

Year	Number of Irrigators	Volume (MCF)	NonDeflated Price (Dollars)	Deflated Price (Dollars)
1974	938	3,361,205	0.54	0.67
1975	969	3,599,215	0.68	0.76
1976	976	3,620,854	0.88	0.94
1977	971	3,113,894	1.18	1.18
1978	950	2,828,903	1.71	1.58
1979	945	2,140,551	1.98	1.65
1980	944	1,723,459	3.56	2.62
1981	914	1,522,210	4.01	2.67
1982	743	1,018,171	4.83	3.03
1983	660	771,450	4.33	2.64

Source: Nelson, J. R., R. J. Schatzer and R. Jobes, 1985.

TABLE III

TOTAL IRRIGATED ACRES AND NUMBERS BY TYPES OF IRRIGATION SYSTEM AND CROP FOR BEAVER, TEXAS AND CIMARRON COUNTIES AND THE STATE OF OKLAHOMA

County	Irrigated Groundwater	Gravity Flow	Central Pivot System	Sideroll	Grain Sorghum	Wheat	Alfalfa	Corn	# of Farms Gravity Systems	# of Farms Having Sprinkler Systems	# of Farms Using Sprinkler Systems
1983											
Beaver	33,600	8,304	20,046	5,250	11,295	14,483	3,200	--	20	84	70
Texas	171,780	129,060	42,640	500	60,000	80,000	12,000	6,000	520	200	200
Cimarron	130,900	102,000	30,000	--	49,600	64,000	2,000	3,000	200	25	14
TOTAL	336,280	239,364	92,686	5,750	120,895	158,483	17,200	9,000	740	309	284
STATE TOTAL	625,401	350,161	218,907	118,025	147,190	216,255	101,861	13,790	1,487	4,010	3,364
1981											
Beaver	31,600	12,500	12,480	--	20,400	5,655	3,480	700	72	133	--
Texas	279,280	244,711	34,839	--	95,750	117,000	17,000	31,900	456	170	--
Cimarron	103,090	81,900	22,750	--	70,000	23,000	1,700	12,000	270	45	--
TOTAL	412,970	339,111	70,069	--	186,150	145,655	22,180	44,600	798	348	--
STATE TOTAL	760,249	470,405	207,058	--	222,666	201,995	136,232	48,502	1,890	4,200	--

Source: 1981 and 1983 Irrigation Survey Oklahoma.

Table III also shows a large reduction in gravity flow irrigation of almost 100,000 acres while central pivot system irrigation increased by approximately 22,000 acres, indicating a shift from labor intensive to capital intensive irrigation.

The increasing number of central pivot systems in the Oklahoma Panhandle dictates the importance of considering the unique characteristics of the central pivot system for studies with applications for the future. Therefore, this study analyzes irrigation applications by central pivot systems.

The number of farms with gravity flow or sprinkler systems in Beaver and Cimarron Counties declined while the number in Texas County increased from 1981 to 1983 (Table III). However, the total number of farms for the three counties declined by about 40 in each category.

Declining water supplies, increasing energy costs and low market prices have combined to reduce the economic life of irrigation water throughout the Great Plains. In the Oklahoma Panhandle, the reduction of irrigated grain sorghum acreage is of particular concern. Research on the proper timing of irrigation applications has increased substantially in recent years. Often soil and plant models are used to determine the response of various irrigation strategies with limited amounts of water applied. As irrigations are reduced, plant water stress is simulated and the tradeoffs between reduced water use and reduced crop yields and their combined effect on profitability may be evaluated.

A Review of Irrigation Scheduling Techniques

Over the years many different techniques for scheduling irrigations have been developed and used. At the farm level irrigation scheduling techniques range from irrigating when crop leaves begin to curl to a computerized system which calculates water needs and starts and shuts down a number of different irrigation systems (Larson, 1983).

Reliable irrigation decisions have been obtained from simple methods such as measuring evaporation from a wash tub pan. This measurement of evapotranspiration (ET) can give individual applicators an indication of plant water use in the field and assist in determining when to irrigate and how much water to apply (Westesen and Hansen, 1981). The checkbook method, developed in the mid 1970's, utilizes crop coefficients, daily maximum air temperature and solar radiation in conjunction with the model developed by Jensen, Wright and Pratt (1970) as a simplified scheduling technique (Lundstrom, Stegman and Warner, 1981).

Others have used mathematical equations to estimate plant growth. Hanks (1974) assumed that only transpiration directly influences plant growth while asserting that evaporation and drainage have an indirect effect on available water and thus transpiration. Soybean yields have also been based on accumulated transpiration using climatic data (Hill, Johnson and Ryan, 1979).

Many irrigation scheduling models have been contingent on evapotranspiration equations where both plant transpiration and evaporation from the soil are assumed important. Wright (1981) notes that improved ET crop coefficients developed from lysimeter data should be usable in estimating ET in areas with climates similar to that of south central Idaho. In the Central Great Plains a linear relationship was found between ET and yield for wheat, millet and grain sorghum (Hanks, Gardner and Florian, 1969). Jensen, Wright and Pratt (1971) concluded that the combination of equations using daily meterological data results in daily estimates of evapotranspiration appropriate for scheduling irrigations. Jensen and Wright (1971) also compare estimated daily ET with expected mean daily ET.

Harrington and Heerman (1981) note that state of the art computer programs can be used to calculate ET from recorded climatic data as well as use rainfall and irrigation amounts to calculate daily depletions in a field and thereby schedule future irrigations. Crop Care Associates uses a computerized ET modeling approach to irrigation scheduling which is responsive to variations in wind movement and humidity (Brase, Horgensen and Jardine, 1981).

Still others have used soil moisture estimates to schedule irrigations. Jensen, Wright and Pratt (1970) made date of irrigation estimates based on an equation including the estimated depletion of soil moisture and the mean rate of ET during the stages of plant growth. Controlling high-frequency irrigations by achieving a soil matrix potential function which limits deep percolation to near zero was demonstrated by Phene, et al. (1981).

Boggess, et al. (1981) developed a model in which irrigations are scheduled if the water content in the root zone of the soil drops below some threshold value specified by the user. Cary (1981) also predicted irrigation dates contingent on the depletion of water in the root zone and the decrease of water potential. The USDA-ARS Irrigation Scheduling Program developed by Jensen, Wright and Pratt (1970), provides estimates of the timing and amount of water needed using weather data and simple data on crop and soil situation.

Some of the more recent technology in irrigation scheduling includes infrared (IR) thermometry. Pinter and Reginto (1981) suggest that IR thermometry is a reliable surrogate for certain physiologically-based water stress measurements. Since an entire field can be surveyed in a very short period of time, IR thermometry appears to offer enormous potential for scheduling irrigations on a cost effective basis (Jackson, et al., 1980). Hatfield (1981) also indicates that IR thermometry could easily replace more labor and time-intensive methods.

While these previously mentioned irrigation scheduling techniques have shown success in predicting when to irrigate they have not considered the economic impact of irrigation versus stressing the crop. A review of other research where economic analysis is performed is discussed later in this study. Within this body of research there has not been a model developed which can derive, on a daily basis, the optimal timing and quantity of irrigation applications under varied input and output price conditions.

Objectives

The overall objective is to develop an irrigation simulation model which can be used to obtain irrigation schedules which will maximize net returns for irrigated grain sorghum in the Oklahoma Panhandle. The specific objectives are:

1. To modify the grain sorghum plant growth model developed by Arkin, Vanderlip, and Ritchie for utilization on a microcomputer and application under soil, climatic and topological conditions in the Oklahoma Panhandle.

2. To determine the relationship between plant development and timing of irrigation applications and precipitation.

3. To modify the grain sorghum plant growth model in order to allow for daily updating and feedback of soil, climatic, irrigation, and plant conditions.

4. To modify the grain sorghum plant growth model for dynamic optimization of net returns during the growing season.

5. To derive optimal irrigation schedules under varying fuel prices, irrigation efficiencies and market prices.

Summary of Procedures

The basic intent of this analysis is the development of a dynamic simulation model that can run on a microcomputer to evaluate day to day irrigation decisions. Since a grain sorghum plant growth simulation model had already been developed and documented by Maas and Arkin (1980), the task was greatly reduced.

The first procedure was to adapt the plant growth model for use on a microcomputer. Once on the microcomputer a dynamic programming recursive algorithm was developed for the grain sorghum plant growth model. This algorithm enables the model to evaluate alternative irrigation schedules within the deterministic environment. Because of the nature of the day to day calculation and feedback characteristics of the model, expectations for the future need only be developed for the next few days and the model can be updated as new information becomes available. However, if information is available for the entire growing season the model will derive the optimal irrigation schedule for the whole year.

The study also compares the optimal irrigation schedules, as derived from the recursive algorithm over a 23-year period, with alternative irrigation scheduling techniques.

Chapter II is a discussion of the conceptual theory used in this study. It includes the relevant concepts of marginal analysis and behavioral theory at the firm level. Systems dynamic modeling, simulation analysis and dynamic programming are also presented.

Chapter III presents the dynamic programming simulation model used in this analysis. Within this section is an identification of the appropriate data needed for the model as well as a detailed description of the development and workings of the model.

Chapter IV identifies the various conditions under which optimal irrigation schedules are derived and compared to previous methods of obtaining irrigation schedules and also presents the empirical results of the irrigation schedules. Within this chapter, the irrigation schedules are analyzed and benefit of the model and new irrigation technology are evaluated.

Chapter V deals with the summary and conclusions as well as any limitations and recommendations for further research.

CHAPTER II

CONCEPTUAL FRAMEWORK

Marginal Analysis

Decision making at the firm level is traditionally modeled as a perfectly competitive market with the objective of profit maximization in the face of given prices and a technologically determined production function. This marginal analysis model is a static model and also assumes unchanging tastes, preferences and technology.

Perfect competition generally exists in the farm economy as producers are price takers in both the input and output markets. In the case of perfect competition, the total value of outputs is linearly related to the quantity of output, i.e., quantity of output times the market price taken by the producer.

Baumol (1970) sites three alternatives under which a firm may vary inputs and outputs in order to maximize profits:

1. The firm can increase output by increasing one or more inputs,
2. The firm can increase some output at the expense of another,
3. The firm can substitute one input for another.

These three cases are commonly referred to as the Factor-Product Model, the Product-Product Model and the Factor-Factor Model.

The Factor-Product Model is the appropriate model for a profit maximizer to use in evaluating the optimal quantity of water to distribute to the crop. The marginal analysis optimality condition in the Factor-Product Model is that the price ratio of any factor-product combination must equal the marginal product for the particular factor-product combination. In other words, profits are maximum when the marginal value product is equal to the price of the input assuming second order conditions are satisfied.

Figure 2 indicates the impacts that changes in grain sorghum prices and irrigation water costs may have on a profit maximizer's use of his water resources. Since the marginal value product is the marginal product of grain sorghum times the price of grain sorghum, an increase in the price of grain sorghum will shift the MVP curve upward to MVP_1. This will result in an increase from w to w_1 in the optimal quantity irrigation water applied. As per acre-inch irrigation costs rise from increased fuel prices and/or a declining water table, the marginal factor cost may rise from MFC to MFC', leading to a reduced optimal water application to w'.

The above marginal analysis is applicable to yearly water use as well as daily water applications. However, the static marginal analysis model is less useful in analyzing the dynamic nature of irrigated agricultural crops. The production function for irrigated crops is dependent not only on soil moisture but on a host of other input variables such as temperature, humidity, solar radiation, wind speed, soil fertility, and competitive insects and weeds. A two dimensional production function of irrigated grain sorghum might resemble that in Figure 3.

A production function could be estimated for the irrigated crop based on varied water applications with all other variables fixed.

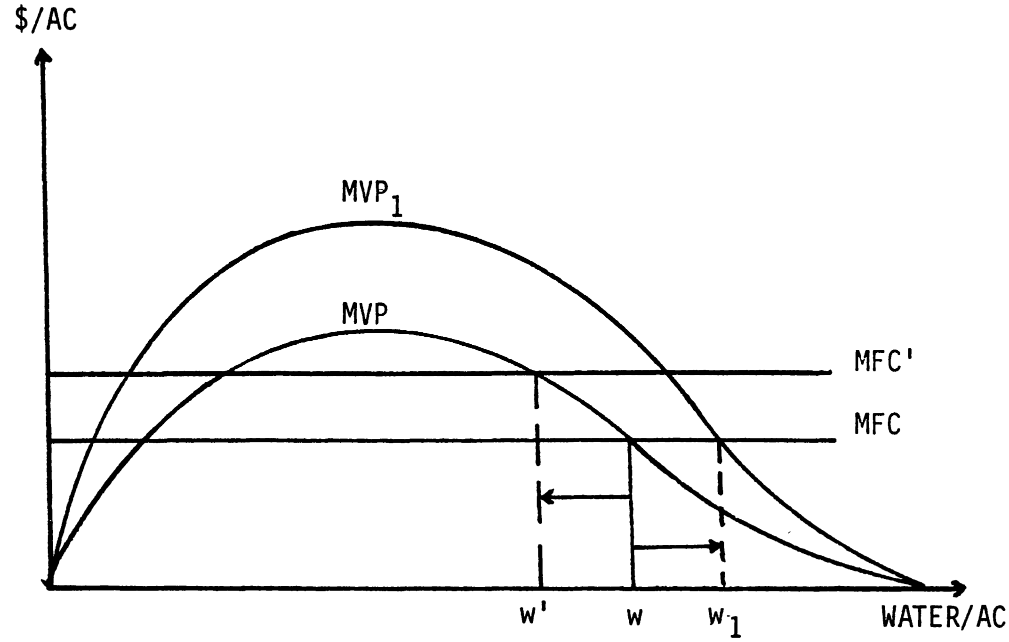

Figure 2. Optimal Irrigation Quantity Under Different Grain Sorghum Prices and Water Cost Using Marginal Value Product and Marginal Factor Cost

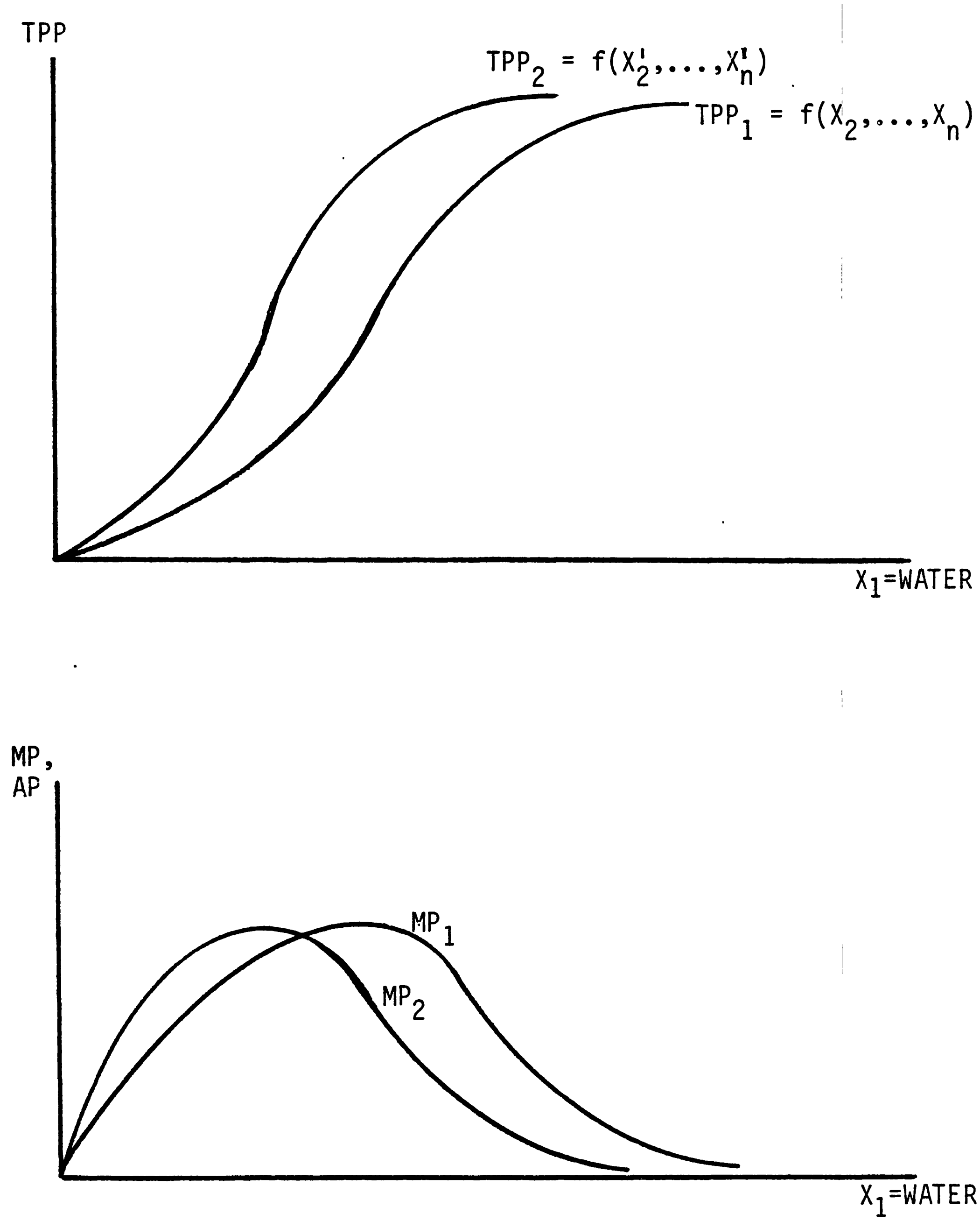

Figure 3. The Effect of Input Changes on Total Physical Product and Marginal Physical Product

However, this production function would still not account for the dynamic nature of the timing of irrigation applications. Even with the production function TPP_1, a change in any other input (x_2, x_3,..., x_n) will result in a new production function, TPP_2, and with it a new marginal product curve.

Naturally a multi-dimensional production function could be estimated but would not be a trivial task with all the inputs that need to be considered. Even then, one would still be confined to a static model which cannot account for the timing of inputs throughout the growing season.

Timing of inputs as well as the quantity of inputs is an important decision to be made at the firm level. Marginal analysis alone is not capable of handling the significant impact of the timing of irrigation applications. Also the timing of inputs may not be a profit maximizing decision but rather a utility maximizing decision as the optimal time to apply water to the crop may come during the decision maker's leisure time or diminish some other goal. This leads us to behavioral theory at the firm level.

Behavioral Theory at the Firm Level

The theory of the firm in general is an attempt to explain the way in which resources are allocated by a price system and is thus primarily a theory of markets. In conjunction with the profit maximization and perfect knowledge assumptions of marginal analysis, the rationality assumptions of the firm implies that firms maximize the discounted value of future profits, and they have perfect knowledge only up to a probability distribution of all possible future states of the world (Cyert and March, 1963). In otherwords, the decision maker at the firm level does not know all future states but rather has conceived a set of probabilities and a distribution for the future states. Each firm may have its own subjective probabilities and distributions.

Whereas marginal analysis assumes timelessness, decision making at the firm level occurs in a dynamic environment. Likewise, profit maximization may not be the primary objective of the firm. Large public corporations may be more concerned with maximizing the price of their stock (Brigham, 1982). In the case of smaller firms, utility maximization may be the objective and thus the owner/operator's leisure time may be an important objective along with profits, or they may simply wish to reduce the variability or riskiness of returns. In this context, Anderson, Dillon and Hardaker (1977) assert that risk has a significant impact on the way in which resources should be allocated under expected utility maximization. Patrick, Blake and Whitaker (1983) also provide evidence that farmers view goals in a multi-dimensional framework.

In addition to understanding the nature in which decisions are made at the firm level, one needs a method or way in which to model those decisions. Such a method should be adaptable to the stochastic nature of the firm's environment. Although much of the recent literature has focused on stochastic dominance or efficiency (King and Oamek, 1983; Pope and Ziemer, 1984; Cochran, Robinson and Lodwick, 1985; and Klemme, 1985) and risk averse producers or managers (King and Lybecker, 1983; Moffit, et al., 1984; Apland, Barnes and Justus, 1984; and, Karp and Pope, 1984), this study assumes risk neutrality.

Antle asserts that the analysis of dynamic uncertain models shows that farmers' optimal decisions are affected by risk, whether they are "risk-neutral" of "risk-averse." He further states that dynamic, risk-neutral models may prove more useful than conventional static risk-averse models for understanding the role production risk plays in farm management and may especially be more useful if farmers do not know how risk affects production.

Systems dynamics is used to develop the theoretical background for modeling the irrigation decision process in a dynamic environment.

Systems Dynamic Modeling

The general system theory may be described as a method of developing a systematic theoretical framework for describing general relationships of the empirical world. The systems approach has much more emphasis on planning than does Behavioral Theory.

A system is considered as a set of interdependent objects united to perform a specific function (Pritsker and Pegden, 1979). In the context of an irrigation system this could be thought of as the pump and central pivot unit operating together to deliver water to the plant.

A control is the function of the system which provides adjustments in conformance to the plan. There are four major elements of a control system:

1. A characteristic or condition to be controlled, such as the soil moisture level.

2. A sensor or a way to measure the condition, like a neutron probe or tensiometer.

3. A comparator or device that compares the measurement with the plan, for instance a computer model.

4. An activator or a device or individual that brings about change, the irrigation system.

The two major classifications of systems are open systems and feedback systems. An open system is one characterized by outputs that respond to inputs but where the outputs are isolated from and have no influence on the inputs. The grain sorghum plant, taken by itself, is an open system in that it reacts to inputs (nutrients, water, climatic conditions) but has no influence over these inputs. Likewise, the irrigation system is an open system, because if left alone it will continue to apply water to the crop whether the plant needs it or not.

In contrast a closed loop or feedback system, is influenced by its own past behavior. Negative feedback systems are goal seeking and respond as a consequence of failing to achieve that goal. Positive feedback generates growth processes wherein action builds a result that generates still greater action. Richardson and Pugh, 1981 state that organizations, economies, and in fact all human systems are feedback systems.

The feedback loop, as depicted in Figure 4 is a closed path connecting in sequence a decision that controls action, the level of the system, and information about the system (Forrester, 1968). In this simple feedback diagram the model must begin with some initial conditions or an outside source. The level of soil moisture or current state is positively related to the rate of irrigation. As more water is applied the soil moisture level increases. Information is also a level in this system. The information about the soil

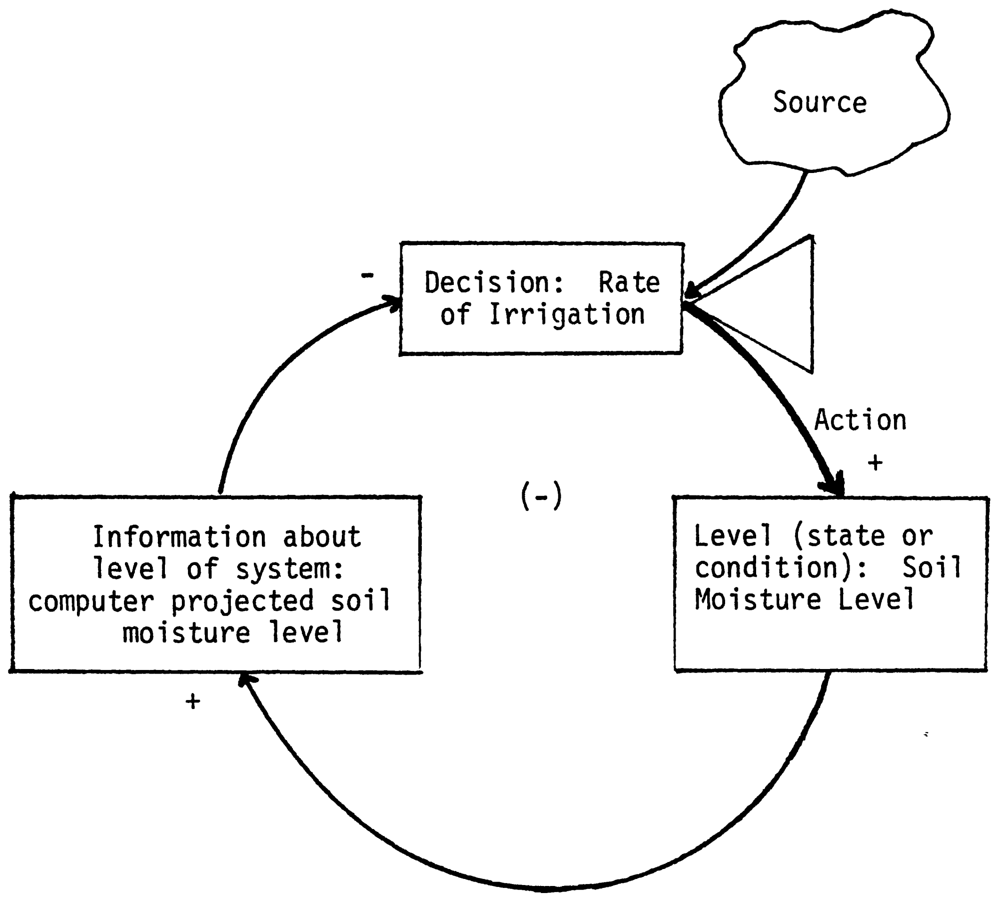

Figure 4. A Negative Feedback Loop for Irrigation Decisions

moisture level is, at least we hope, positively related to the actual state of the system. As the information indicates that the soil moisture level has increased the decision is to decrease the rate of irrigation application. Thus there exist a negative relation between the information level and the decision. With two positive relations and one negative this closed path is a negative feedback loop.

While the grain sorghum plant is an "open" system, the modeling of that plant should be a negative feedback system in that it tries to achieve the goal of imitating the observed plant development. On the other hand, dynamic programming of irrigated grain sorghum can be a positive feedback in that it attempts to generate action which will build results that generate maximum net returns.

Computer modeling, simulation, and policy analysis promise to realize their greatest potential when they are combined with understandings and applications of the concept of feedback (Richardson and Pugh, 1981).

Simulation Analysis

As a system is a set of objects performing a specific function, models are descriptions of systems. Pritsker and Pegden (1979) identify three types of models. They may be scaled physical objects (iconic models), graphical representations (visual models) or mathematical equations and relations (abstract models). Economic models fall in the category of abstract models.

Simulation is essentially a technique that involves setting up a model of a real situation or system and then performing experiments on the model by either direct experimentation with the system itself or direct analytical solution of some problem associated with the system. In the context of this study, a simulation model is a mathematical representation of a system (irrigated grain sorghum), which can be exercised in an experimental fashion on a digital computer (in this case a microcomputer).

Mathematical models of economic systems consist of four well-defined elements: components, variables, parameters, and functional relationships (Orcutt, 1960). The variables appearing in economic simulation models are used to relate one component to another and are often classified as exogenous variables, status variables, and endogenous variables. Exogenous variables are the independent or input variables of the model and are assumed to have been predetermined and given independently of the system being modeled. In other words, exogenous variables are determined from outside the system. These variables may be regarded as acting upon the system but not being acted on by the system.

Endogenous variables can be classified as either controllable or noncontrollable. Controllable (or instrumental) variables are those variables that can be manipulated or controlled by the decision makers or policy makers of the system. Noncontrollable variables are generated by the environment in which the modeled system exists and not by the system itself.

Status variables describe the state of a system or one of its components either at the beginning of a time period, at the end of a time period, or during a time period.

In deterministic models neither the exogenous variables nor the endogenous variables are permitted to be random variables and the operating characteristics are assumed to be exact relationships rather than probability density functions. Those models in which at least one of the operating characteristics is given by a probability function are said to be stochastic models. Static models are models which do not explicitly take the variable time into consideration. Mathematical models that deal with time-varying interactions are said to be dynamic models.

All simulation models need to be both verified and validated. Verification is determining whether a simulation model performs as intended, as in debugging the computer program. Although verification is simple in concept, debugging a large-scale simulation model can be quite an arduous task (Law and Kelton, 1982).

Law and Kelton (1982) discuss five techniques which can be used in debugging the computer program of a simulation model:

1. Write and debug the computer program in subprograms.

2. Have more than one person read the computer program.

3. Use a trace procedure to debug the simulation model.

4. Run the model under simplifying assumptions for which the model's true characteristics are known and can easily be computed.

5. With some types of simulation models, it may be helpful to display the simulation output on a graphics terminal as the simulation actually progresses.

Validation, on the other hand, is determining whether the simulation model is an accurate representation of the real-world system under study. For validating simulation models, Law and Kelton outline a three-step approach:

1. Develop a model with high face validity.

2. Test the assumptions of the model empirically.

3. Determine how representative the simulation output data are.

However, one should note that model validity is a relative matter and it cannot be proven that any model is an exact representation of reality.

Simulation combined with the system dynamics approach to modeling a problem can provide a very realistic representation of the real world situation. However, analysis with this type of approach is only useful for "what if" scenarios. Therefore, an additional technique is needed to obtain the optimal decisions during the simulation of the real world situation. The technique used in this study is dynamic programming.

Dynamic Programming

The term "dynamic programming" was coined by Bellman in 1957 to describe the mathematical theory of multi-stage decision processes. In a physical system through the course of time the system is subject to change, meaning that the variables within the system undergo transformations. The decision process in dynamic programming according to Bellman (1957) is described as the case where there is a choice of the transformations which may be applied to the system at any time. The stage of the decision process is the interval into which it is divided, whereas the state of the process, at a particular stage, describes the condition of the process, and is defined by the magnitudes of state variables and/or qualitative characteristics (Burt and Allison, 1963).

Two types of decision processes generally occur in dynamic programming: single-stage and multi-stage. With regard to an irrigation decision, a multi-stage decision process would be one in which we must first choose whether to irrigate, then how much to irrigate and finally what day to begin the irrigation. However, by carefully selecting the states and stages of the system this decision can be simplified to a single-stage decision process whereby the choice is between a number of alternative irrigation scenarios where each scenario contains its own values for quantity of water and date to begin the irrigation, with one scenario having a zero value for quantity of water applied.

In dynamic programming each decision may be thought of as a choice of a certain number of variables which determine the transformation to be employed; each sequence, of choices or policy, is a choice of a larger set of variables. By lumping all the choices together the problem is reduced to a classical one of determining the maximum of a given function (Bellman, 1957). The policy is thus evaluated by this function. The dynamic model includes the following:

1. A physical system characterized at any stage by a set of parameters called the state variables.

2. A choice of a number of decisions at each stage of the process.

3. The effect of a decision is the transformation of the state variables.

4. Past history of the system is of no importance in determining future actions.

5. The purpose of the process is to maximize some function of the state variables.

Bellman (1957) notes that in some problems the state variables and the transformations are forced upon us; in others there is a choice in these matters and the analytic solution stands or falls upon this choice; in still others, the state variables and sometimes the transformations must be artificially constructed.

A policy is defined as any rule for making decisions which yields an allowable sequence of decisions. An optimal policy maximizes a preassigned function of the final state variables. These definitions lead to Bellman's Principle of Optimality (1957):

> An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision.

The common characteristic of all dynamic programming models is expressing the decision problem by means of a recursive formulation (Wagner, 1975). Such a recursive formula for a relatively simple dynamic programming problem might take the following form.

$$f_n(s) = \text{MAX}[R_{sj} + f_{n-1}(j)] \qquad \text{for } n = 1,2,\ldots,N$$

where

$f_n(s)$ = maximum returns when in state s with n more stages to go.

R_{sj} = the returns associated with moving from state s to state j.

Therefore the entire recursive formula, expressed in words, states that one should compare each possible sum of the policy returns for the immediate stage, going from state s to state j, and the optimal policy returns of arriving in state j with only n-1 more stages to go to the final decision.

It often happens that one type of mathematical model is well suited to one type of analytic approach and not another. Generally the three principle parts of a mathematical model, the conceptual, analytic, and computational aspects, must be considered simultaneously and not separately (Bellman and Dreyfus, 1962). This is especially true when considering the amount of time required to arrive at the optimal solution. By taking advantage of individual structural features, one can always cut down on the time required, along with increasing accuracy and realistic features of the model.

Bellman and Dreyfus (1962) also note that the actual decision process may possess several optimal policies. In some cases, merely the maximum return and optimal policy are desired; in other cases, all optimal policies may be important and may be prized more highly than the maximum return itself.

In contrast to a direct enumeration analysis, the technique of dynamic programming allows one to easily and quickly resolve problems of more complex nature than the direct enumeration method. For a simple situation where each of the independent variables can run over ten different values, the N-variables maximization process will then involve 10^N different sets of choices. By doubling the length or number of stages to 2N the sets of choices increase multiplicatively in dimension by 10^N times. Likewise a doubling of the number of different values will increase the sets to 20^N. If N is equal to ten stages this is a multiplicative increase to 1000 times the original problem. However, it should be noted that the total number of possibilities is actually less since a choice of one independent variable immediately restricts the possible ranges of the other variables.

Application of the functional equation technique in dynamic programming is equivalent to using a search process that is far more efficient than the mathematical examination of all cases. Bellman and Dreyfus (1962) again indicate that it is the principle of optimality that furnishes the key. Having chosen an initial x_n, we do not then examine all policies involving that choice of x_n, but rather only those policies which are optimal for an N-1 stage process with variables $x-x_n$. In this way, processes remain additive rather than multiplicative. The time required for a twenty-stage process is now almost precisely twice the time for a ten stage process.

CHAPTER III

MODEL DEVELOPMENT

To predict the growth of an agricultural crop such as grain sorghum, one must have a mathematical model for anticipating the relationships that occur in the environment. One might naturally assume that more accurate predictions will come from the more realistic and often complex models. Although this may be a very good assumption a model that is too complicated may desire a vast amount of data and be too difficult to implement or use.

Dynamic Recursion Algorithm

Some of the earliest agricultural applications of dynamic programming were conducted by Oscar R. Burt. In 1963, Burt and Allison set out to "indicate the importance of dynamic programming and the magnitude of its potential application in the realm of farm management decisions by presenting a complete model for the analysis of a problem of economic significance." Since then Burt has used dynamic programming to analyze resource use applied to ground water (Burt, 1964a), conjuctive use of ground and surface water (Burt, 1964b), the impact of pasture and range investments (Burt, 1971), ground water management and surface water development for irrigation (Burt, 1976), natural resource management (Burt and Cummings, 1972), U.S. wheat stocks and exports (Burt, Koo and Dudley, 1980), and soil conservation (Burt, 1981).

Taylor and Burt (1984) developed near-optimal decision rules, with dynamic programming, for controlling wild oats in spring wheat. Taylor (1983) also used stochastic dynamic programming to prove the certainty equivalence nature of his optimal fertilizer application problem, while Taylor and Talpaz (1979) examined U.S. wheat storage policies with certainty equivalence dynamic programming and stochastic simulation.

Recently others have developed a dynamic approach to optimizing irrigation applications. Bekure and Eidman (1971) used a recursive model in formulating the optimal intertemporal allocation of ground water in the Central Ogallala Formation as a multi-stage sequential decision process. Yaron and Dinar (1982) combined linear and dynamic programming to calculate the optimal allocation of irrigation water over time. A dynamic corn model was designed by Morgan, Biere, and Kanemasu (1980) to analyze irrigation strategies as well as dryland strategies where rainfall patterns are known in a stochastic sense. Raju, et al. (1980) expanded on this dynamic corn model by adding a dynamic programming formulation to maximize net returns based on the state variables accumulated growth and available soil water. The contributions of variance in enterprise net returns from soybean price and yield, marginal cost of irrigation, and amount of irrigation water applied were examined by Boggess, et al. (1983) using a dynamic simulation model.

In still other studies, that did not include dynamic programming, Feinerman and Knapp (1983) investigated the magnitude of benefits from groundwater management and Knapp (1984) obtained optimal water quantities and soil salinities in steady state. Using optimal control and stochastic dominance theory, Harris (1981) was able to analyze irrigation schedules for grain sorghum.

Harris (1981) was able to obtain optimal irrigation quantities (between 1 and 3 inches) using optimal control when irrigations were initiated based on soil moisture conditions and Raju, et al. (1980) obtained the optimal number of irrigations during the growing season based on a pre-set quantity per application. However, these two factors have not been combined into a single dynamic model.

The model developed for this study is a combined simulation and deterministic Dynamic Programming (DP) Model with a negative feedback subroutine. This analysis incorporates the grain sorghum plant growth model, developed by Arkin, Vanderlip and Ritchie (1976), with an irrigation component and a recursive dynamic programming optimization algorithm.

Applying Antle's (1983) discussion to the context of irrigation strategies, once irrigation decisions are made, natural or environmental and economic conditions change and previously optimal decisions, based on old information become suboptimal with new information. With the feedback subroutine the user can update plant growth and soil moisture conditions at any point in the growing season, thus entering the new information into the model as it becomes available. Daily climatic conditions can also be updated as they become obtainable. Although probability distributions for future weather events may seem desirable, using expected values allows the model to remain relatively simple and "user friendly" so that it can be implemented at the farm level.

Conceptualization difficulties, or understanding how to formulate the empirical situation, is the greatest obstacle to applications of dynamic programming (Burt, 1982). The grain sorghum production model is multi-stage and involves output dynamics. Using the equations developed by Antle, output dynamics takes on the following form:

$$Q_t = f\,[X_t, Q_{t-1}, Q_{t-2}, \cdots, u_t]$$

where

Q_t = output or growth of grain sorghum in period t.

X_t = the input vector in period t.

u_t = the random production shock in period t.

The growth in each period is additive to the growth in the previous period and is also a function of the input vector, which includes the irrigation quantity and the random shock, or stochastic prices and weather. In the deterministic model, this random shock is accounted for by using expected prices and weather. Feedback of actual climatic and growth data assures that the appropriate past periods output or growth (Q_{t-1}, Q_{t-2},...) are used to derive current output.

The DP subroutine in the model analyzes six different alternative irrigation strategies at each stage in order to derive the optimal irrigation schedule for a producer in the expected environment. This subroutine can be altered to examine other irrigations, but naturally the larger the number of paths that must be compared to find the optimal path, the more time it takes to run the program. On a microcomputer time can be a very important factor.

In order to include varying irrigation application quantities within the DP subroutine, six irrigation alternatives were included in the formulation. These include a no irrigation option and three different levels of irrigation (1.4", 2.1" and 2.8") with varied timing of the irrigations. All irrigation levels are in terms of gross water applied in inches. In contrast to dynamic programming, a direct enumeration analysis would mean that one must examine either no irrigation on day i or starting a 1.4 inch, 2.1 inch or 2.8 inch application on day i. This would have to be performed for every day of the growing season or for i = 160 to 250, involving 90^4 alternatives to evaluate. Since the grain sorghum model, on the microcomputer with current technology, takes approximately one minute to solve one year of plant growth, this direct enumeration method would require some what more than 10^6 hours, or approximately 178 years to calculate.

However, as noted by Bellman (1957), a choice of x_n immediately restricts the possible ranges of the other x_i. In other words if we choose to evaluate irrigating 1.4 inches on day 180 the next irrigation cannot begin until day 184 so that we have reduced the total number of possibilities.

For the reduced direct enumeration analysis, we consider that it takes approximately eight days to apply the 2.8 inch application. Thus using a common denominator of eight days there are six possible scenarios within the eight day period:

1. No irrigation.
2. Irrigate 1.4 inches in the first four days.
3. Irrigate 1.4 inches in the last four days.
4. Irrigate 1.4 inches in the first four days and 1.4 inches in the last four days.

5. Irrigate 2.1 inches in the first six days.

6. Irrigate 2.8 inches over the eight days.

This reduces the number of periods in which the alternatives need evaluating to 90/8 or approximately 11. Thus, leaving 11^6 alternatives, or something more than 29,500 hours of computations equaling about 4.8 years to complete the calculations for the direct enumeration approach. This is the minimum amount of time that the direct enumeration method could be performed. In the actual case there would be between 11^6 and 90^6 alternatives because as long as the no irrigation alternative is chosen time advances to day i+1 and again the six scenarios are evaluated. If the no irrigation alternative is chosen throughout the year, 90^6 alternatives are evaluated. If an irrigation scenario is chosen every time, approximately 11^6 alternatives are evaluated.

Thanks to Bellman's (1957) principle of optimality, the time required for dynamic programming is additive rather than multiplicative. Therefore one would expect the evaluation of the six alternatives to take only five minutes longer than the one minute it takes to run the model for a single alternative.

Following from the previous discussion, the dynamic programming recursive algorithm used in this study works on an eight day basis to optimize the net value of plant growth throughout the growing season. The objective function for the dynamic programming algorithm is the following:

$$\text{Max } r_{ij} \quad \text{for days } i = \text{SPROUT, SPROUT} + 1, \ldots, \text{IMAX}$$
$$\text{and } j < i$$

where

r_{ij} = ps_i * wg_i - pw_j* w_j

r_{ij} = the expected revenue from the plant calculated on day j less the associated cost incurred from day i to j

ps_i = expected selling price of grain sorghum

wg_i = the weight of grain sorghum grain on day j

pw_j = variable cost of water per acre inch on day i

w_j = acre inches of water applied on day j.

SPROUT = the day the first plant leaf appears

IMAX = the day plant maturity occurs.

However, the grain sorghum plant does not produce any grain weight until the fourth stage of its 5 stages of plant growth. So up until grain production begins the following formula is used

$$r_{ij} = ps_i * d_i * tw_i - pw_j * w_j$$

where

d_i = total plant weight to maturity grain weight coefficient on day i

tw_i = total weight of grain sorghum plant on day i

The total weight to maturity grain weight coefficient is estimated by stage of plant growth from a general linear model. Twenty-three years of grain sorghum plant growth is simulated with the SORGF model under five conditions. In the first condition, irrigations are initiated anytime the soil moisture reaches the critical level of 45 percent. For the next four conditions, no irrigations occur during stage k for k equal to 1, 2, 3, and 4. The 23 years of total plant weight and grain weight for each of the last four conditions is compared one at a time to the first condition, where irrigations occur in all stages, to determine the impact of withholding irrigations during each of the 4 stages. Based on the t statistics, the intercept term was found to be insignificant, or in other words, the null hypothesis that the intercept is equal to zero is not rejected. Therefore, the general linear model is forced through the origin with the following form:

$$DTWG_i = B_k * DTOWT_k \quad \text{for } k = 1, 2, 3, 4$$

where

$DTWG_k$ = the maturity grain weight when irrigations are initiated at the 45 percent moisture level in all plant growth stages minus the maturity grain weight when no irrigations are allowed in Stage k of plant growth but are initiated at the 45 percent moisture level in all other stages.

$DTOTWT_k$ = the total plant weight at the end of Stage k of plant growth when irrigations are initiated at the 45 percent moisture level minus the total plant weight in Stage k when no irrigations occur in Stage k.

B_k = the coefficient of the difference in total plant weight in Stage k of plant growth to the difference in maturity grain weight at the end of the season.

The estimated coefficient values are given in Table IV. The B_3 value of .507 indicates that if the difference in the total plant weight between the scenario where irrigations occur in all stages and

TABLE IV

GENERAL LINEAR MODEL COEFFICIENTS OF TOTAL PLANT WEIGHT TO MATURITY GAIN WEIGHT WHEN IRRIGATIONS ARE WITHHELD IN VARIOUS STAGES

Stage	B_1	B_2	B_3	B_4	R^2
1	.093 (7.500)[a]				.862
2		.144 (12.760)			.962
3			.507 (8.990)		.862
4				.996 (474.400)	.999

[a]Values in parentheses are t values for the null hypothesis that the coefficient is equal to zero.

the scenarios where they occur in Stages 1, 2 and 4, is 1 gram, the difference in grain weight at maturity is .507 grams.

In order to derive the d_i values in the above equation, the DP model was run for different discrete multiples of the B_k's to find those values which yield maximum net revenue over 23 years of simulated plant growth. The resulting d_i coefficients by stage of plant growth are given as:

d_i = .186 for i = days in Stage 1

d_i = .288 for i = days in Stage 2

d_i = 1.014 for i = days in Stage 3

d_i = 2.000 for i = days in Stage 4

The d_i value of .288 indicates that additional plant growth on day i in Stage 2 of 1 gram is expected to increase maturity grain weight by .288 grams.

The previously mentioned objective function leads to the dynamic programming recursion:

$G(n) = \text{Maximum } [r_{nk} + G(k)]$

for n = SPROUT, SPROUT + 1,..., IMAX

G(SPROUT) = 0

G(n) = the maximum expected net revenue policy in state n

where

r_{nk} = the expected revenue for moving from state k to state n

The daily path associated with six alternative irrigation strategies is shown in Figure 5. Over the eight day recursion the six alternative irrigation strategies are:

1. Eight days of no irrigation

$$G(8) = \sum_{n=1}^{8} r_{nk} + G(0) \qquad k = n-1$$

or path r_{10}, r_{21}, r_{32}, r_{43}, r_{54}, r_{65}, r_{76}, r_{87}

2. Irrigate 1.4 inches beginning on day 4

$$G(8) = r_{nk} + G(4) \qquad n = 8 \text{ and } k = n-4$$

or path r_{10}, r_{21}, r_{32}, r_{43}, r_{84}

where

$$G(4) = \sum_{n=1}^{4} r_{nk} + G(0) \qquad k = n-1$$

3. Irrigate 1.4 inches beginning on day 0 and 1.4 inches beginning on day 4

$$G(8) = \sum_{n=4,8} r_{nk} + G(0) \qquad k = n-4$$

or path r_{40}, r_{84}

4. Irrigate 1.4 inches beginning on day 0

$$G(8) = \sum_{n=5}^{8} r_{nk} + G(4) \qquad k = n-1$$

or path r_{40}, r_{54}, r_{65}, r_{76}, r_{87}

where

$$G(4) = r_{nk} + G(0) \qquad n = 4 \text{ and } k = n-4$$

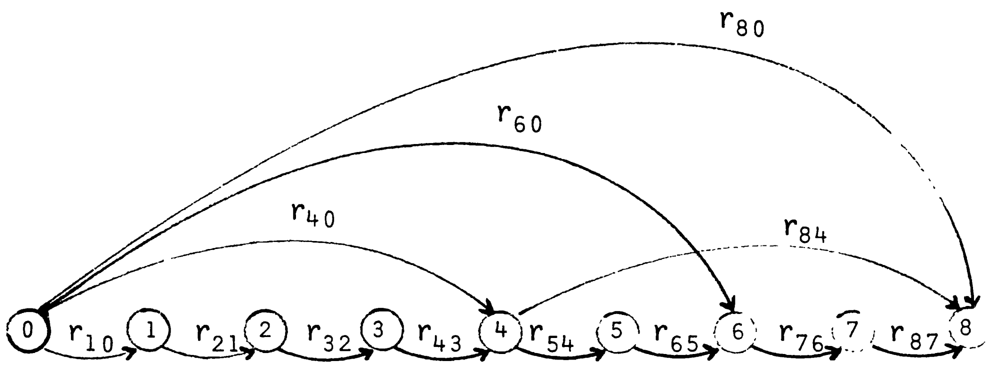

Figure 5. Daily Path for Six Alternative Irrigation Decisions

5. Irrigate 2.1 inches beginning on day 0

$$G(8) = \sum_{n=7}^{8} r_{nk} + G(6) \qquad k = n-1$$

or path r_{60}, r_{76}, r_{87}

where

$$G(6) = r_{nk} + G(0) \qquad n = 6 \text{ and } k = n-6$$

6. Irrigate 2.8 inches beginning on day 0

$$G(8) = r_{nk} + G(0) \qquad n = 8 \text{ and } k = n-8$$

or path r_{80}

If the no irrigation alternative is selected as optimal on day 8 then the model advances one day and finds the maximum G(9). However, if any one of the other five irrigation strategies is selected the model advances eight days to day 16 and obtains the optimal G(16). This feature is incorporated into the model because a new irrigation cannot begin until the current one has been completed by day 8. Therefore there is no reason to evaluate the alternative until n-8 is greater than day 8.

Also within the recursive algorithm is a modification to allow a preplant or postplant preemergence irrigation if insufficient moisture is available to germinate the plant. If the emergence has not occurred under the no irrigation alternative four days after planting, then the objective is to maximize the value of only the five irrigation alternatives. This modification insures that the first plant leaf appears within four days of planting.

Grain Sorghum Plant Growth Model

The plant growth component in this analysis is used to simulate the daily growth of grain sorghum based on climatic and soil moisture conditions. The original version of the grain sorghum plant growth model was developed by Arkin, Vanderlip and Ritchie (1976) with later modifications resulting in the model now known as SORGF (Maas and Arkin, 1978).

The growth model, as depicted in Figure 6, begins each year of simulation on May 1 by accepting plant, soil, planting location, and climatic data. Included in the climatic data are values for minimum and maximum temperature, precipitation, and solar radiation. Each day of the growing season is incremented in the model based on calendar days.

Until planting has occurred the model calculates soil moisture on a daily basis within the EVAP and SOLWAT subroutines. The EVAP subroutine calculates the potential evaporation for each day. After potential evaporation is calculated the soil water balance is computed in the SOLWAT subroutine. Daily soil moisture is derived from the following equation:

$$SW_t = SW_{t-1} - ET_t + RAIN_t + IR_t$$

where

SW_t is extractable soil water in period t

SW_{t-1} is extractable soil water in period t-1

ET_t is evapotranspiration in period t

$RAIN_t$ is precipitation in period t, and

IR_t is quantity of irrigation water applied in period t.

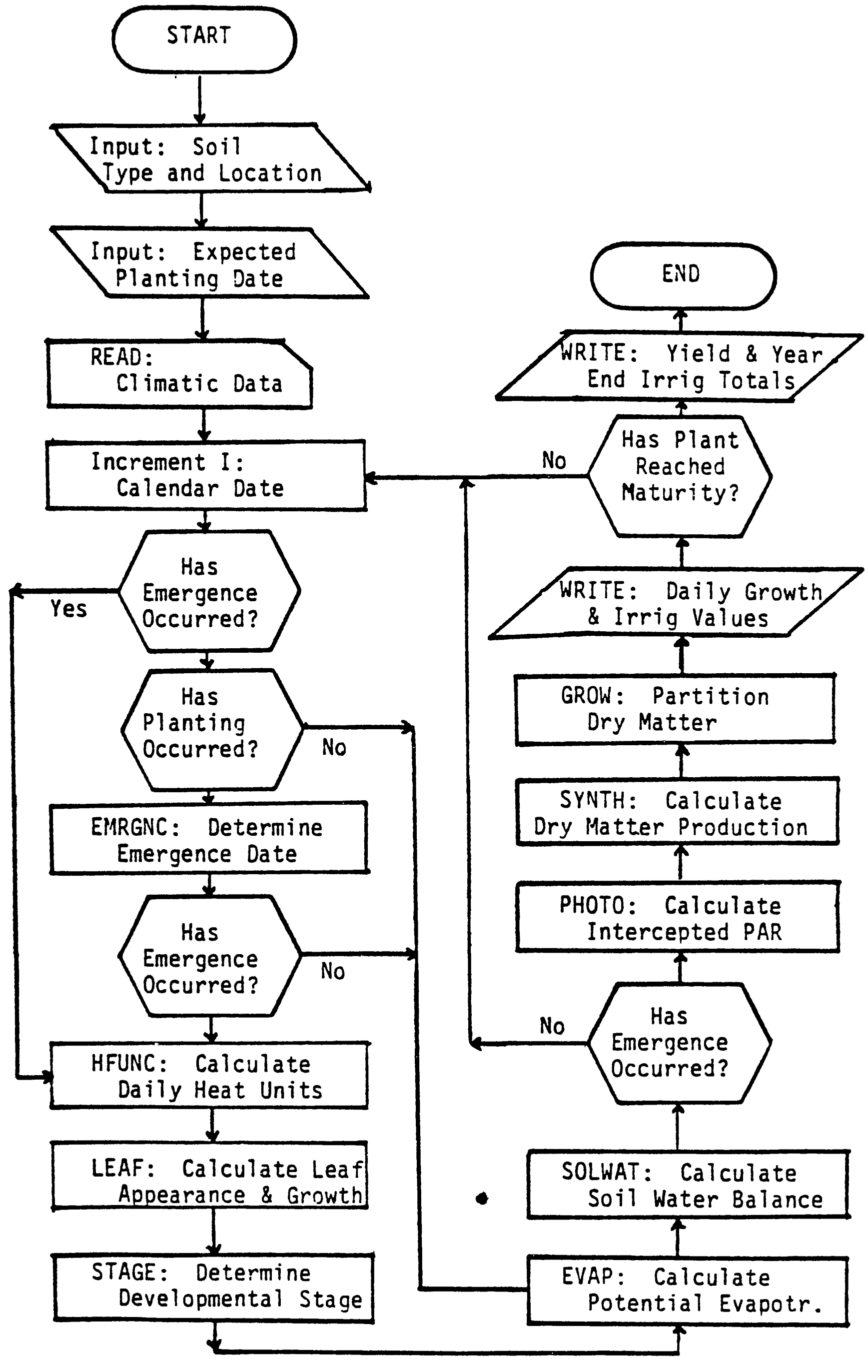

Figure 6. Flowchart of Grain Sorghum Plant Growth Model

The daily extractable soil moisture ratio is equal to the extractable soil water level (SW) divided by the upper limit extractable soil water level (UL). These UL values vary by soil type. The grain sorghum growth model's normalized yields are insensitive to normalized extractable soil moisture ratios above 45 percent, but show an increasing reduction in normalized yields below a ratio of 30 percent (Maas and Arkin, 1980).

Subroutine EMRGNC is called by the main program after planting to determine the date on which the modeled sorghum plant emerges above the soil surface. Within this subroutine the model first determines the date of seed germination with both germination and emergence being a function of accumulated heat units. Germination is influenced by available soil moisture while the emergence date is also a function of planting depth. If insufficient moisture is available in the soil the seed can lay dormant until a rain or pre-emergence irrigation application triggers germination.

Prior to germination heat units are accumulated using a base temperature of 6.3^{o} Celsius (C). After germination, in the emergence portion of the subroutine heat units accumulate above a base temperature of 11.4^{o} C. The emergence of the first leaf coincides with the emergence of the plant.

Until plant emergence has occurred the model next calls the EVAP and SOLWAT subroutines. After emergence of the first grain sorghum leaf, subroutine HFUNC calculates the daily accumulation of heat units above a base temperature. Heat units are used in the subroutine LEAF for daily leaf development. Heat units accumulate based on the following rules. If the minimum temperature is greater than the base temperature of 7.0^{0} C, the daily heat units is equal to the average temperature for that day minus the base temperature. If the maximum daily temperature is less than the base temperature, no heat units accumulate. When the base temperature falls between the minimum and maximum daily temperature a sine curve is used to calculate heat units.

The leaf subroutine in SORGF determines both the calendar date on which leaves appear and the daily leaf area of each leaf up until maximum leaf area is obtained. In this subroutine leaf emergence is based upon accumulation of heat units. A total of 50 heat units above a base temperature of 7.0^{0} C is required to initiate a new leaf.

Accumulation of leaf area by emerged leaves is a function of ambient temperature (Arkin, Vanderlip and Ritchie, 1976). The daily increase in leaf area is added to the leaf area from the previous day. When the current leaf area for a particular leaf exceeds that leaf's maximum leaf area, growth of that leaf is considered to be complete. The date of maximum leaf area occurrence is recorded for each leaf by the model.

For each leaf beyond number 11 completely grown, a corresponding leaf, starting at number 1, is lost. Total leaf area is calculated by the model with total area reductions occurring when individual leaves are lost.

Upon computing leaf appearance and area, the model determines the phenological stage of growth for the grain sorghum plant. The five stages for grain sorghum are defined as:

1. Emergence to differentiation.
2. Differentiation to end of leaf growth.

3. End of leaf growth to anthesis.
4. Anthesis to physiological maturity.
5. physiological maturity and beyond.

Dates of occurrence of each stage of growth are reported by the model.

After the subroutine STAGE is called by the model, potential evaporation and the soil water balance are again computed before PHOTO is summoned by the main program. In this subroutine the intercepted photosynthetically active radiation (PAR) and potential photosynthesis are determined for each calendar day. Potential net photosythesis is defined as the net CO_2 fixed during daylight hours on a ground area basis for nonlimiting water and temperature condition (Arkin, Vanderlip and Ritchie, 1976). The number of hours of sunlight is calculated based on geographic and astronomical factors. The fraction of sunlight transmitted by the sorghum canopy is a function of leaf area index and row spacing (Arkin, Ritchie and Maas, 1978).

Potential photosynthesis is converted into dry matter weight within the SYNTH subroutine. In the final subroutine, GROW, the partitioning of dry matter, produced in SYNTH, to various plant organs is determined. The fraction of dry weight allocated to any particular plant part varies according to the stage of plant development.

Until plant maturity is reached the model begins simulation for the next calendar day. When the plant does reach maturity the end of year yield and weight of plant parts are reported.

Irrigation Components of SORGF

Two irrigation subroutines, XAET and XIRRT as shown in Figure 7, were added to SORGF by Harris. These subroutines are used to schedule

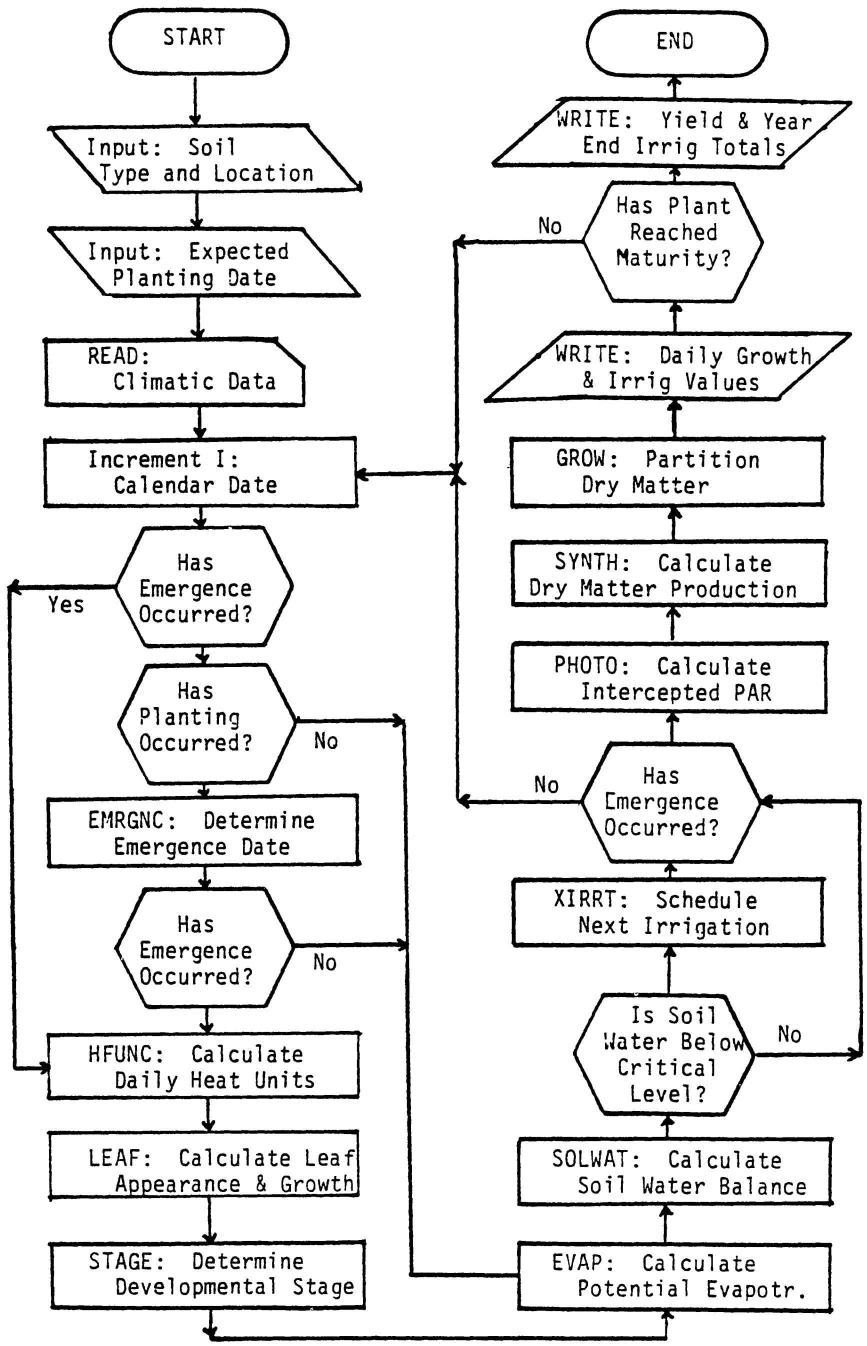

Figure 7. Flowchart of Grain Sorghum Plant Growth Model With Irrigation Scheduling Subroutines

irrigations when the extractable soil moisture reaches a prespecified level. The irrigation subroutines have since been modified by this author to calculate the number of hours required for the a central pivot system to irrigate a specified number of acres. These figures are computed from the following formula (The Irrigation Association, 1983):

$$H = \frac{d * A * K}{Q}$$

where

H = time of one lateral revolution in hours

A = area irrigated in acres

K = constant equal to 453

Q = flow into the central pivot in gpm

d = gross water applied in inches.

In the study by Harris, irrigations were initiated based on the following decision variable calculated in subroutine XAET:

$$XN = (SW - SWS) / AET$$

where

XN = the number of days until the soil moisture reaches the pre-specified critical level.

SW = the current available soil water.

SWS = the critical soil moisture level.

AET = the average evapotranspiration over the previous seven days.

If XN is less than H/24, the number of days to apply a gross application of d inches, then an irrigation activity is initiated. The irrigation application is added as precipitation to the plant growth model on the day following that on which the irrigation activity is initiated. A second irrigation activity cannot begin until H/24 days after the previous activity is initiated.

Harris also added a subroutine forcing the model to delay irrigations during pre-specified stages of growth. This version of the model was used to derive stochastically efficient sets of proposed irrigation schedules, based on stressing the crop during particular stages of growth, and to compare them with the contemporary practice of applying 24 inches of ground water annually (Harris and Mapp, 1981).

Within this study a three inch irrigation occurred whenever the soil moisture level dropped below the critical extractable soil moisture ratio, as specified for that particular irrigation schedule. Six of the twelve proposed irrigation schedules were found to be stochastically dominant by the first degree over the contemporary practice with two others dominant by the second degree. However, Harris and Mapp (1981) concede that their study does not derive an optimal irrigation schedule, but instead derives sets of irrigation schedules that risk averse producers would prefer.

Data

Climatic Data

The plant growth simulation model used in this study requires daily climatic data that can be obtained or estimated for most areas of the country. Climatic data used in this study include daily values for minimum and maximum temperature, precipitation and solar radiation. Although temperature and precipitation data are available for the Oklahoma Panhandle, through the Goodwell Research Station, solar radiation data have only recently become available at that site. Therefore, the 23 years of temperature, precipitation, and solar radiation data is obtained for Dodge City, Kansas. These data are provided by the National Climatic Center, Asheville, North Carolina.

Minimum and maximum daily temperature are read into the model in degrees Fahrenheit and converted to Celsius temperature for calculations within the model. The plant growth model also converts daily precipitation from inches to centimeters for employment in calculating the daily soil moisture conditions. Solar radiation data from the U.S. Department of Commerce (1978) are recorded in joules per squared meter and converted to langleys for use in the grain sorghum plant growth model.

Beginning Soil Moisture

As indicated in the previous chapter, feedback models need an outside source from which to draw the initial conditions or levels for the model. The beginning soil moisture level is such an outside source.

The predominant irrigable clay loam soil in the three county study area is a Richfield clay loam. Water held at field capacity for this soil is 16.3 inches and the permanent wilting point occurs at 8.69 inches as obtained from Goodwell, Oklahoma (Mapp, et al., 1975). In many studies the beginning soil moisture level is assumed to be at field capacity. However, for this study the beginning soil moisture level, at the first of May of each year, is obtained from the following equation estimated by Mapp, et al. (1975):

$$SM_{bm} = 8.69 + 0.22R_{ma} + 2.33R_{1wa}$$

where

SM_{bm} = soil moisture content at the beginning of May.

R_{ma} = rainfall during the month of April.

R_{1wa} = rainfall during the last week of April

The soil water that can be extracted by the plant (extractable soil water) at the beginning of May for these soils is:

$$SW_{bm} = SM_{bm} - 8.7$$

where

8.7 inches is the difference between field capacity and the permanent wilting point.

Irrigation Costs

Irrigation fixed and variable costs are calculated by the Oklahoma State University Irrigation Cost Generator developed by Kletke, Harris, and Mapp (1978). This computer program derives costs on a per acre-inch and per acre basis under various assumptions regarding the irrigation well, fuel source, distribution system, and water requirements. For this analysis, costs are computed for a typical quarter mile central pivot system capable of irrigating 130 acres. The pump is assumed to provide 900 gallons of water per minute to the irrigation system, while a light industrial natural gas engine draws the water from 360 feet.

Natural gas prices are based on the range in natural gas prices that irrigators in the Oklahoma Panhandle are currently paying. Three discrete prices of $2.60, $3.80 and $5.00 per million cubic foot (MCF) are used in the analysis.

Irrigation Efficiency

Water application efficiency is the ratio of the quantity of water effectively put into the crop root zone and utilized by growing crops to the quantity delivered to the field, expressed as a decimal. The quantity delivered to the field is determined as the amount of water pumped into the irrigation system. As noted in the previous section this is 900 gallons per minute.

Irrigation application losses may be any one or a combination of the following four factors (The Irrigation Association, 1983):

1. Evaporation losses from the surface of flowing water or evaporation in the air from sprinkler nozzle spray.

2. Losses to deep percolation below the root zone.

3. Evaporation from the soil during irrigation, or

4. Runoff from the field.

An irrigation system properly designed for a particular field and soil condition should eliminate runoff and possibly any loss to deep percolation. When operated according to design criteria and under favorable climatic conditions, properly designed irrigation systems are capable of water application efficiencies of 65 to 75 percent (Schwab, 1983). More recent studies on Low Energy Precision

Application (LEPA) sprinkler systems have shown application efficiencies of 95 to 98 percent (Stoecker, 1985; and Ellis, Lacewell and Reneau, 1984).

Production Costs and Market Prices of Grain Sorghum

For simulating irrigated grain sorghum production a row spacing of 30 inches, plant population of 100,000 per acre, and a maximum of 17 leaves per plant with maximum leaf areas as indicated in Table V are assumed for the plant growth model. Production costs, in 1985 dollars, exclusive of irrigation application costs, are $130.73 per acre as calculated from Oklahoma Crop and Livestock Budgets (1979). The market prices for grain sorghum are taken from 1985 cash prices, but are varied in later analysis for optimum irrigation schedules under varying conditions.

Verification

As mentioned in Chapter II, verification determines whether a simulation model performs as intended. Three major verifications are necessary with this particular model:

1. Verification of the microcomputer version of SORGF.

2. Verifying that the DP subroutines do not alter the daily calculations within SORGF.

3. Verifying that the dynamic recursion algorithm is capable of finding the optimal solution.

The first step of model development was transferring the SORGF model from the FORTRAN WATFIV language, as used the IBM 3081D, to

TABLE V

INPUT DATA REQUIRED FOR THE GRAIN SORGHUM PLANT GROWTH MODEL

Data Required	Data Value
I. Plant Data	
A. Leaf number	17
B. Maximum individual leaf area ($cm.^2$)[a]	
Leaf 1	0.88
Leaf 2	2.30
Leaf 3	7.60
Leaf 4	12.30
Leaf 5	22.80
Leaf 6	42.50
Leaf 7	69.50
Leaf 8	113.00
Leaf 9	170.80
Leaf 10	248.80
Leaf 11	287.00
Leaf 12	357.50
Leaf 13	336.50
Leaf 14	340.80
Leaf 15	272.30
Leaf 16	209.30
Leaf 17	116.00
II. Planting Data	
A. Planting Date	June 15
B. Plant population (plants/acre)	100,000
C. Row width (inches)	30
III. Climatic Data (daily values from planting until maturity)	
A. Maximum daily temperature (^oC)	b
B. Minimum daily temperature (^oC)	b
C. Solar radiation (ly/day)	b
D. Rainfall (cm/day)	b
IV. Soil Data	
A. Available water holding capacity (inches)	7.63
B. Initial available water content (inches)	c
V. Location Data	
A. Latitude (degrees)	37^o

[a]Values for maximum leaf area from referenced manual by Maas and Arkin, 1978.

[b]Daily values from Dodge City, Kansas weather station.

[c]Value for each individual year calculated from referenced study by Mapp, et al.

PASCAL and an 8-bit microcomputer. The model now runs on a 16-bit microcomputer. As Law and Kelton suggested, programming the model in PASCAL was performed one subroutine at a time. When the model was initially transferred into the PASCAL language by this author, there was no one else available who understood PASCAL and could read the reprogrammed version of SORGF. Therefore, debugging complex segments of the program was accomplished by talking to individuals who knew the WATFIV language to insure that the logic of the program statement had been understood properly and then transferred into the PASCAL language with the same meaning. Tracing the variable values through the subroutines greatly diminished the problem of finding typographical and logic errors. In order to satisfy the fourth technique cited by Law and Kelton (1982), the model was run under the assumption used in Harris's (1981) study of a three inch irrigation whenever the soil moisture level falls below the critical soil moisture ratio of 45 percent. The PASCAL model on the microcomputer computed the year end yield within plus or minus one-tenth of a pound of that calculated in the original WATFIV version on the IBM 3081D. The net return of plus or minus one cent was considered satisfactory to complete this verification step.

The second major step of the verification process was to check that the recursive nature of the dynamic programming algorithm did not alter the day to day calculations of the SORGF model. Although most programming efforts fail to work correctly the first time, this was not a particularly difficult debugging problem. This part of the model was verified by "backing the model up in time," as the recursive algorithm does, to insure that all the important dynamic variable values could be retrieved. This method of jumping back in time was performed over different intervals (i.e., i-4 and i-8) on a continuous basis throughout the simulation year, and also on a one time basis at important time events. For example at planting, emergence, and stage dates the model was run a few days past the event and then jumped back to four or eight days before that event to insure that the second time through the event occurred on the same day and with the same variable values. This technique was also performed, on a one time jump, from end to beginning of the model. In every case year end results were exactly the same as they were for the original model.

The final verification step was to insure that the dynamic programming algorithm can find the optimal irrigation schedule. Obtaining the "true" optimal policy, the one which maximizes net revenue under all conditions, is not a straightforward task. With the conventional backward DP method, the N^{th}, or terminal stage is known in advance and the recursion works backward from this stage to the first stage. However, the nature of grain sorghum plant growth is such that the maturity date (terminal stage) is unknown until it occurs. Therefore, this model is developed as forward dynamic programming which makes it more difficult to find the "true" optimal policy without examining all possible paths to the terminal stage through direct enumeration. Since direct enumeration was estimated to take between 4.8 years and 178 years to calculate, this method of verification was eliminated. Instead the dynamic recursion algorithm was tested for its ability to obtain the optimal policy for maximum yield. In this case the objective function becomes:

$$\text{Max } r_{ij} = wg_i \quad \text{for days } i=\text{SPROUT, SPROUT} + 1,\ldots, \text{IMAX and } wg_i > 0$$

$$\text{Max } r_{ij} = tw_i \quad \text{for days } i=\text{SPROUT, SPROUT} + 1,\ldots, \text{IMAX and } wg_i = 0$$

This optimum policy is then compared with running the SORGF model and irrigating any time the soil moisture level falls below the upper limit of extractable soil moisture in order to insure that the soil profile remains full of water. The hypothesis here is that as long as water is not limiting, maximum yields should result for the given climatic conditions. Since quantity of water applied per application could also be a factor, the nonlimiting water scenarios are run with three different gross application quantities, 1.4 inches, 2.1 inches and 2.8 inches.

The maximum total weight scenario for the DP model and the three scenarios for the SORGF model are shown in Tables VI and VII. In every one of the 23 years, the dynamic recursive algorithm obtains the maximum yield with less water than the full soil profile scenarios. From these results it is concluded that the algorithm should also derive the irrigation schedules which maximize net returns. The DP models' maximum yield scenario is very similar to the current practice in the Oklahoma Panhandle of applying 24 inches of water per year.

In evaluating pasture and range investments with a DP model, Burt (1971) noted that the results of numerical problems can only be suggestive, but the results in his study did not discourage using the approximately optimal policy. Therefore, as Bellman and Dreyfus (1962) indicate, approximate optimal policies which yield returns to

TABLE VI

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD AND IRRIGATION QUANTITIES UNDER THE OBJECTIVE OF MAXIMIZING YIELD FOR THE DYNAMIC PROGRAMMING AND SORGF IRRIGATION SCHEDULING MODELS

	-----------MTW DP--------			----------MTW1 SF-------- IRRIG QUANTITY = 1.4"			----------MTW2 DP-------- IRRIG QUANTITY = 2 1"			----------MTW2 SF-------- IRRIG QUANTITY = 2 8"		
YEAR	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES
1	60 89	25.20	18 90	60 90	30.80	23.10	60 90	31.50	23.62	60 89	33 60	25 20
2	56 40	25 20	18 90	56 39	26 60	19 95	56 40	27 30	20.47	56 40	28 00	21 00
3	62 97	26.60	19.95	62.97	30.80	23 10	62 97	31 50	23 62	62 97	33 60	25 20
4	62 13	25 20	18.90	62.14	29 40	22.05	62.14	29 40	22 05	62 14	30 80	23 10
5	61 88	28 00	21 00	61.88	30 80	23 10	61 87	31 50	23 62	61 87	33 60	25 20
6	65 49	23 80	17 85	65.49	33 60	25 20	65 49	35 70	26.77	65 49	36 40	27 30
7	66 89	26.60	19.95	66.89	32 20	24 15	66 89	33.60	25 20	66.89	33 60	25 20
8	65 69	29 40	22 05	65.69	32.20	24 15	65.69	33 60	25.20	65 69	33.60	25 20
9	55 39	25 20	18 90	55.39	32 20	24 15	55 39	33 60	25 20	55 39	33 60	25 20
10	55 95	25 20	18 90	55.95	33.60	25 20	55.95	33 60	25 20	55 95	36 40	27 30
11	56 61	24.50	18.37	56 61	29 40	22 05	56 61	29 40	22 05	56 61	30 80	23 10
12	52 63	22 40	16.80	52.64	28 00	21 00	52 63	29.40	22 05	52.63	30 80	23 10
13	55 74	24.50	18 37	55.74	32 20	24.15	55.74	33.60	25.20	55 74	33.60	25 20
14	51 95	24 50	18.37	51 95	28 00	21.00	51.95	29.40	22.05	51 95	30.80	23 10
15	51 37	28 00	21.00	51 37	33 60	25.20	51 37	33 60	25 20	51 37	36 40	27.30
16	53.02	26 60	19 95	53.02	32.20	24.15	53.02	33.60	25 20	53 02	33 60	25 20
17	50.47	23.80	17 85	50.34	29.40	22.05	50 34	31 50	23 62	50.34	30 80	23 10
18	64 72	26 60	19.95	64.71	29.40	22.05	64.72	31 50	23 62	64 72	30.80	23 10
19	72 08	25 20	18.90	72 08	32.20	24.15	72 08	33.60	25 20	72 08	33 60	25 20
20	49 78	23 80	17 85	49 78	33 60	25.20	49 78	35 70	26 77	49 78	36 40	27 30
21	63 11	26 60	19 95	63.11	30 80	23 10	63 10	31 50	23 62	62 87	33 60	25 20
22	52.13	23 80	17.85	52 13	28 00	21 00	52 13	29 40	22 05	52 13	30 80	23 10
23	65 85	25 20	18.90	65 85	32 20	24 15	65 85	33 60	25.20	65 85	33 60	25 20

TABLE VII

PRICES OF GRAIN SORGHUM AND NATURAL GAS, IRRIGATION VARIABLE COST AND IRRIGATION APPLICATION EFFICIENCY FOR THE BASE SCENARIO

		MTW DP				MTW1 SF IRRIG QUANTITY = 1.4"				MTW2 DP IRRIG QUANTITY = 2.1"				MTW2 SF IRRIG QUANTITY = 2.8"			
		MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
.	UNITS																
YIELD	CWT/AC	58.83	6.35	49.78	72.08	58.83	6.36	49.78	72.08	58.83	6.36	49.78	72.08	58.82	6.35	49.78	72.08
WATER PUMPED	INCHES	25.47	1.63	22.40	29.40	30.92	2.06	26.60	33.60	32 05	2.21	27.30	35.70	32.99	2.23	28.00	36.40
EFFECT WATER	INCHES	19.10	1.22	16.80	22.05	23.19	1.55	19.95	25.20	24.03	1.66	20.47	26.77	24 74	1.67	21.00	27.30
PRE-EMERGE	INCHES	2.74	0.29	1.40	2.80	3.29	0.68	2.80	4.20	4.29	0.44	4.20	6.30	5.60	0.00	5.60	5.60
STAGE 1	INCHES	7.33	1.35	4.20	9.80	9.62	1.06	8.40	12.60	9.68	1.22	8.40	12.60	9.25	1.32	8.40	11.20
STAGE 2	INCHES	5.42	0.77	2.80	7.00	5.84	0.81	4.20	7.00	5.66	0.99	4.20	6.30	5.84	0.81	5.60	8.40
STAGE 3	INCHES	4.35	0.94	2.80	5.60	4.44	0.69	2.80	5.60	4.57	1.03	2.10	6.30	4.63	1.36	2.80	5.60
STAGE 4	INCHES	5.63	1.00	4.20	7.00	7.73	0.83	5.60	8 40	7.85	0.94	6.30	8.40	7.67	1.26	5.60	8.40
1.4" IRRIG	#	11.78	5.29	1.00	19.00	22.09	1.47	19.00	24.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.1" IRRIG	#	0.22	0.52	0.00	2.00	0.00	0.00	0.00	0.00	15.26	1.05	13.00	17.00	0 00	0.00	0.00	0.00
2.8" IRRIG	#	3.04	2.40	0.00	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	11.78	0.80	10.00	13.00

within one percent of the actual maximum may be as important or even more important than the true optimal solution in furnishing simple approximations for complex situations.

Validation

The primary concern in validation is with the plant growth simulation component of the model, which is the segment of the model which must represent the real-world or actual plant growth in the field. It is believed that the authors of the grain sorghum growth model developed a model with high face validity (Arkin, Vanderlip and Ritchie, 1976). To test the assumptions of the model empirically, sensitivity analysis of SORGF was performed on many of the parameters within the model (Maas and Arkin, 1980). Simulation parameter values were also compared to observed values while using no feedback, the feedback updating technique at growing point differentiation and at half-bloom (Arkin, Maas and Richardson, 1980). Findings show that the use of feedback does not eliminate all the error in parameter values, but feedback generally does result in predicted parameter values closer to their respective observed values. Also, Harris (1981) compared the simulated yields and variability of yields for dryland and contemporary irrigations with those occurring in the Oklahoma Panhandle.

Since the microcomputer version of the model is verified with the original SORGF model, and SORGF has been validated we assume that the microcomputer DP model is also validated and ready to derive optimal irrigation strategies.

CHAPTER IV

ANALYSIS AND RESULTS

The dynamic programming model and the SORGF model are run for a variety of irrigation conditions in order to derive and evaluate optimal irrigation schedules. Irrigation schedules and net revenues from the SORGF model are used to evaluate whether the DP model obtains optimal irrigation schedules. Twenty-three years of actual climatic data are used to elicit 23 replications for each irrigation scenario. All total revenue values reported in this chapter are grain sorghum yield times market price. Net revenue is total revenue minus the $130.73 of production costs less the variable irrigation cost. This value is defined as the net return to all fixed costs.

The analysis of results is divided into four separate sections. The first part of the analysis involves comparing the results from the dynamic programming model to results obtained from the SORGF irrigation scheduling model using several different critical soil moisture ratios. Next, the two models are run and compared under various grain sorghum market prices, natural gas prices and irrigation application efficiencies. The third segment of the analysis of results is a contrasting of the DP model's output under the various market prices, natural gas prices and irrigation application efficiencies. The final section is concerned with the impact of advances in types of central pivot irrigation systems and their improved efficiency on the optimal irrigation schedule derived by the

DP model. Irrigation cost output for all the scenarios analyzed is presented in Appendix A by scenario identification.

Comparisons of mean values from the results are made with the paired t-test. The null hypothesis that the difference in the two means is equal to zero, assuming that the populations are normally distributed, are tested with the following criteria from Steel and Torrie (1960):

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_{\bar{x}_1 - \bar{x}_2}} = \frac{\bar{d}}{S_{\bar{d}}}$$

where

$\bar{x}_1$ = the mean from the first population

$\bar{x}_2$ = the mean from the second population

$\bar{d}$ = the difference in the two means

$S_{\bar{d}}$ = the standard deviation appropriate to a difference between two random means from a normal population

and

$$S_{\bar{d}} = \sqrt{\frac{\sum_j D_j^2 - (\Sigma D_j{}^2)/n}{n(n-1)}}$$

where

D_j = the difference in the two paired observations for year j

n = the number of years

If rejection of the null hypothesis occurs when a significance level of .05 is used then it is referred to as a significant difference at the 5 percent level. As Steel and Torrie indicate (1960), a rejection of the null hypothesis between the 5 percent and 1 percent level is referred to as "significant" and less than 1 percent as "highly significant."

In the first section of the analysis of results, a mean difference statistic is used to evaluate the irrigation scheduling policy with the highest net revenue. This statistic is as follows:

$$MD_J = 1/n \sum_{n=1}^{i} \text{Max } NR_i - NR_{ij}$$

for

j = 1, 2, ..., m scenarios

i = 1, 2, ..., n years.

where

MD_j = the average difference per year between the scenario with the highest net revenue for years i through n and the net revenue for scenario j for years i through n

NR_{ij} = net revenue for scenario j in year i

Max NR = the maximum net revenue in year i for any of the scenarios j through m.

This statistic indicates the reduction in net revenue from the optimal or maximum returns each year of the particular irrigation policy or scenario. A true optimal irrigation policy should have a MD value of zero over the 23 years of simulation.

The DP Irrigation Scheduling Model Versus the SORGF Irrigation Scheduling Model

This first segment of results focuses on establishing the optimality or near optimality of the DP scheduling model. Simulations are run over 23 years for the base case market price, irrigation variable cost and irrigation application efficiency of \$4.40 per cwt, \$4.16 per acre-inch and 75 percent, respectively as shown in Table

VIII. The SORGF irrigation scheduling model is run using the same base case conditions with irrigations scheduled when soil moisture reaches various critical soil moisture levels.

Maas and Arkin (1980) found that the grain sorghum growth model's normalized yields are insensitive to normalized extractable soil moisture ratios above 45 percent, but show an increasing reduction in normalized yields below a ratio of 30 percent. Therefore, critical extractable soil moisture ratios, employed in the SORGF scheduling model, are for 45 percent and below.

Results for 23 years of the Base DP scenario and SORGF scenarios with five different critical soil moisture ratios are presented in Table IX. Irrigations by inches and numbers for these scenarios are given in Appendix B. Of the six scenarios the DP scheduling model achieves the maximum net revenue in 14 of the 23 years, indicating that the model does not derive the "true" optimal policy. However, it is asserted that it is an approximately optimal policy.

The 45 percent SORGF model, as shown in Table X, derives a mean yield that is higher than the DP model. However, the quantity of irrigation water, 13.24 inches, is a highly significant difference than the DP model's 6.33 inches, making the net revenue greater, $87.45 versus $72.69 per acre, for the DP base scenario.

Comparison of the DP scenario with the SORGF scenarios having critical soil moisture ratios of 30, 25, 20, and 15 percent, indicates significantly higher irrigation quantities for the SORGF scenarios with the increases in applications occurring in pre-emergence and Stage 1 of plant growth. The DP model applies a single 1.4 inch pre-emergence application in only three of the 23 years. The SORGF

TABLE VIII

PRICES OF GRAIN SORGHUM AND NATURAL GAS, IRRIGATION VARIABLE COST AND IRRIGATION APPLICATION EFFICIENCY FOR THE BASE SCENARIO

	Price of Grain Sorghum (cwt)	Price of Natural Gas (MCF)	Irrigation Variable Cost (acre-inch)	Irrigation Efficiency
Base Cost	$4.40	$3.80	$4.16	.75

TABLE IX

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL BASE SCENARIO AND THE SORGF IRRIGATION SCHEDULING MODEL WITH VARIOUS CRITICAL SOIL MOISTURE RATIOS

	BASE DP			B15 SF MOISTURE RATIO = 0.15			B20 SF MOISTURE RATIO = O 20			B25 SF MOISTURE RATIO = O 25		
	YIELD CWT/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE
YEAR												
1	57.26	10.50	77.54[a]	57.71	14.70	62.05	59 03	16 80	59 11	60 00	16 80	63 39
2	52 46	8.40	65.16[a]	54.77	14.70	49.09	55.35	14 70	51.67	55.88	16 80	45 25
3	59.42	7.70	98.70	60.07	8 40	98.62	61.08	10.50	94.32	62.02	10.50	98.47
4	58.79	13.30	72.60[a]	58.09	16.80	54.97	60.38	18 90	56 30	60.94	18.90	58 78
5	59 16	6.30	103 36[a]	58.32	8.40	90.93	60 07	8 40	98.62	60.97	8 40	102 58
6	62.68	4.90	124.68[a]	62.03	6.30	115.99	63.85	6.30	123.99	64.22	8.40	116 88
7	59.51	9.80	90.32	63.29	12.60	95.31	64.81	14.70	93 30	65.85	14.70	97.87[a]
8	61.03	9.10	99.95	61.41	10.50	95.81	63.74	12.60	97 30	64 52	12.60	100.73
9	53 31	4.20	86.37	53.69	4.20	88.04[a]	55.06	6 30	85.34	55.07	6 30	85 38
10	54.48	0.00	108.99[a]	54.48	0.00	108.99[a]	54 48	0 00	108.99[a]	55.43	2.10	104 43
11	53.04	9.10	64.78[a]	54.15	12.60	55 12	55.19	12.60	59 70	55 93	14.70	54 23
12	51.19	2.80	82.85[a]	51.90	4.20	80.16	52.52	6.30	74.15	52.56	6.30	74.35
13	52.37	4.20	82.23	51.22	4.20	77.14	53.87	6.30	80.11	54 59	6.30	83 27
14	49.98	4.20	71.70[a]	51.18	6.30	68.27	51.79	8 40	62.20	51.80	8.40	62.24
15	47.32	2.80	65.84	50.01	4.20	71.83	49.88	6.30	62 55	50 17	6.30	63.80
16	47.38	1.40	71.92	51.43	4.20	78.07	52.39	4.20	82.34	52.74	4 20	83 85[a]
17	48.07	9.10	42.93[a]	49.38	14 70	25.38	49.68	14.70	26.72	49 78	16.80	18.43
18	61.08	12.60	85.61[a]	60.56	16.80	65 84	63.10	18.90	68.30	63.37	18.90	69 47
19	67.32	7.70	133.43[a]	68.46	10.50	126.81	69.63	12.60	123.23	70 99	12.60	129 22
20	49.59	0 00	87.47[a]	49.59	0.00	87.47[a]	49 65	2.10	78 98	49 73	2.10	79 33
21	59.33	6.30	104.10	61 04	8.40	102.90	62 15	8.40	107 79	62 45	8 40	109.09[a]
22	51.46	4.90	75.30[a]	51 97	6 30	71.71	51 97	6 30	71.74	52 05	8 40	63 36
23	61.92	6.30	115.50	62.18	8 40	107.90	63.85	8 40	115 28	64.68	8.40	118 94[a]

TABLE IX (Continued)

	----------B30 SF--------- MOISTURE RATIO = 0.30			----------B45 SF--------- MOISTURE RATIO = 0.45		
YEAR	YIELD CWT/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE
1	60.09	18.90	55.04	60.77	18.90	58 04
2	56.07	16.80	46.08	56.34	18.90	38 55
3	62.51	10.50	100.65[a]	62.89	12.60	93.58
4	61.50	21.00	52.52	62.03	23.10	46 12
5	61.30	10.50	95.33	61.78	12.60	88 67
6	65.03	8.40	120.48	65.36	10.50	113.17
7	66.21	16.80	90.71	66.78	18.90	84.49
8	64.89	12.60	102.79[a]	65.56	14.70	96.60
9	55.03	6.30	85.20	55.35	8.40	77.85
10	55.77	4.20	97.18	55.90	8.40	80.28
11	56.15	14.70	55.18	56.55	16 80	48.21
12	52.56	6.30	74.32	52.58	8.40	65.66
13	55.08	6.30	85.39[a]	55.63	8.40	79.10
14	51.75	8.40	62.04	51.92	10.50	54 02
15	51.16	6.30	68.18	51.22	8.40	59.69
16	52.85	6.30	75.61	52 98	8.40	67.44
17	50 14	18.80	20.02	50.29	18.90	11.93
18	64.26	21.00	64.66	64 64	23.10	57.60
19	71.48	12.60	131.35	71.97	16.80	116.06
20	49.74	2.10	79.41	49.77	4 20	70.80
21	62.75	10.50	101.69	63.05	12.60	94 29
22	52.10	8.40	63.56	52.12	10.50	54.93
23	65 09	10.50	111.97	65 73	10.50	114.82

[a]Indicates the scenario with the maximum net revenue.

TABLE X

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL BASE SCENARIO AND THE SORGF IRRIGATION SCHEDULING MODEL WITH VARIOUS CRITICAL SOIL MOISTURE RATIOS

		BASE DP				B15 SF MOISTURE RATIO = 0.15				B20 SF MOISTURE RATIO = 0.20			
	UNITS	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
YIELD	CWT/AC	55.57	5.59	47.32	67.32	56.39	5.30	49.38	68.46	57.54	5.79	49.65	69.63
WATER PUMPED	INCHES	6.33	3.66	0.00	13.30	8.58	4.98	0.00	16.80	** 9.77	5.13	0.00	18.90
NET REVENUE	$/AC	87.45	21.36	42.93	133.43	81.67	23.96	25.38	126.81	81.83	24.83	26.72	123.99
PRE-EMERGE	INCHES	0.18	0.48	0.00	1.40	* 0.91	1.39	0.00	4.20	** 1.46	1.73	0.00	4.20
STAGE 1	INCHES	0.15	0.52	0.00	2.10	** 1.55	1.58	0.00	4.20	** 1.92	1.78	0.00	4.20
STAGE 2	INCHES	2.16	1.89	0.00	6.30	2.47	1.63	0.00	6.30	2.37	1.71	0.00	4.20
STAGE 3	INCHES	1.98	1.66	0.00	5.60	1.37	1.36	0.00	4.20	1.55	1.14	0.00	4.20
STAGE 4	INCHES	1.86	1.31	0.00	3.50	2.28	1.78	0.00	4.20	2.47	1.97	0.00	6.30
1.4" IRRIG	#	2.39	1.23	0.00	5.00	** 0.00	0.00	0.00	0.00	** 0.00	0.00	0.00	0.00
2.1" IRRIG	#	0.78	0.80	0.00	3.00	** 4.09	2.37	0.00	8.00	** 4.65	2.44	0.00	9.00
2.8" IRRIG	#	0.48	0.67	0.00	2.00	** 0.00	0.00	0.00	0.00	** 0.00	0.00	0.00	0.00
Mean Diff	$/AC	1.89				7.67				7.51			

TABLE X (Continued)

		B25 SF MOISTURE RATIO = 0.25				B30 SF MOISTURE RATIO = 0.30				B45 SF MOISTURE RATIO = 0.45			
		MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
	UNITS												
YIELD	CWT/AC	58.08	6.05	49.73	70.99	58.42	6.18	49.74	71.48	58.75	6.34	49.77	71.97
WATER PUMPED	INCHES	**10.32	5.14	2.10	18.90	**11.14	5.39	2.10	21.00	**13.24	5.24	4.20	23.10
NET REVENUE	$/AC	81.88	26.72	18.43	129.22	79.97	26.27	20.02	131.35	*72.69	25.94	11.93	116.06
PRE-EMERGE	INCHES	**1.73	1.75	0.00	4.20	**2.10	1.90	0.00	4.20	**2.83	1.63	0.00	4.20
STAGE 1	INCHES	**2.19	1.95	0.00	6.30	**2.28	2.19	0.00	6.30	**3.29	2.52	0.00	8.40
STAGE 2	INCHES	2.01	1.73	0.00	6.30	2.47	1.63	0.00	6.30	2.56	1.67	0.00	6.30
STAGE 3	INCHES	2.01	1.34	0.00	4.20	1.83	1.59	0.00	4.20	2.01	1.73	0.00	4.20
STAGE 4	INCHES	2.37	1.59	0.00	4.20	2.47	1.75	0.00	4.20	2.56	1.79	0.00	6.30
1.4" IRRIG	#	**0.00	0.00	0.00	0.00	**0.00	0.00	0.00	0.00	**0.00	0.00	0.00	0.00
2.1" IRRIG	#	**4.91	2.45	1.00	9.00	**5.30	2.57	1.00	10.00	**6.30	2.49	2.00	11.00
2.8" IRRIG	#	**0.00	0.00	0.00	0.00	**0.00	0.00	0.00	0.00	**0.00	0.00	0.00	0.00
Mean Diff	$/AC	7.46				9.34				16.65			

*Indicates a significant difference at 5 percent with the base scenario.

**Indicates a significant difference at 1 percent with the base scenario.

model derives the highest mean yield under each scenario, whereas the DP model obtains the largest average net revenue.

As mentioned earlier, the DP model fails to acquire the maximum revenue in 9 of the 23 years, however it is always close to the maximum in these 9 years as demonstrated by the mean difference statistic. The mean difference statistic is the average difference over the 23 years that each scenario's net revenue is from the maximum net revenue for the year. A scenario with a mean difference value of 0.0 would indicate that it always obtains the maximum net revenue, whereas a mean difference of 10.0 signifies that the scenario's net revenue is on the average $10.00 per acre less than the maximum.

The DP scenario has a mean difference value of $1.89 showing that it is a near optimal policy. Scenario B25 is the second best with $7.46 per acre per year difference while scenarios B20 and B15 follow closely with $7.51 and $7.67, respectively. From this data it is concluded that the DP model derives an approximately optimal scheduling policy under the base case scenario and that initiating irrigation applications at the 25 percent soil moisture ratio is the best policy for the SORGF model under these assumptions. The 25 percent ratio is in line with Harris's finding where he used optimal control theory and found the average optimal ratios over the 23 years for Stages 1 through 4 to be 22.48, 17.80, 19.79, and 17.19 percent, respectively.

In the next section of the analysis, comparing the DP model to the SORGF model, scenario B25-SORGF will be referred to as the base case SORGF scenario or BASE-SORGF. The next step is to compare the two scheduling models under various market prices, irrigation variable costs and irrigation application efficiencies. This comparison is designed to show the advantage of scheduling irrigations with the dynamic programming model under these varied conditions. Identification of the scenarios and their parameter values is given in Table XI, while irrigations by quantities and numbers are shown in Appendix C for these seven scenarios.

Results From the DP and SORGF Irrigation Scheduling Models With Alternate Market Prices

With the current depressed farm economy market prices are a major concern to producers. Most irrigation scheduling techniques fail to consider the impact of market prices on the irrigation decision. Irrigation scheduling models which are based exclusively on soil moisture conditions, evaporative demand, crop stress, etc. show no impact from a change in the market price of the crop. If the price of the crop drops so low that the increased yield from irrigation will not even cover the variable cost of irrigation it would be more profitable, or losses would be minimized, by ceasing all irrigation. However, most irrigation scheduling techniques would recommend continued irrigation.

For this DP model, market price is a state variable within the recursive equation. Therefore, changes in the market price affect the date as well as quantity of irrigation. The SORGF irrigation scheduling model does not include market price in the decision rule and will irrigate on the same dates and with the same quantities no matter what the price of grain sorghum.

TABLE XI

PRICES OF GRAIN SORGHUM AND NATURAL GAS, IRRIGATION VARIABLE COST AND IRRIGATION APPLICATION EFFICIENCY FOR THE SEVEN ALTERNATIVE SCENARIOS

	Price of Grain Sorghum (cwt)	Price of Natural Gas (MCF)	Irrigation Variable Cost (acre-inch)	Irrigation Efficiency
BASE	$4.40	$3.80	$4.16	.75
PGS1	$3.80	$3.80	$4.16	.75
PGS2	$5.00	$3.80	$4.16	.75
IVC1	$4.40	$2.60	$3.40	.75
IVC2	$4.40	$5.00	$4.92	.75
IEF1	$4.40	$3.80	$4.16	.60
IEF2	$4.40	$3.80	$4.16	.90

Table XII depicts results of the DP and SORGF models over the 23 simulated years with market prices of \$3.80 and \$5.00 per cwt. For the lower price the DP model obtains the maximum net revenue in 19 of the 23 years, but with the \$5.00 per cwt market price, it yields the maximum revenue in 12 of 23 years. For those 11 years when the DP model does not obtain the maximum net revenue it is very close to that maximum.

In Table XIII, statistics for the two scheduling models are reported for market prices of \$3.80 and \$5.00 per cwt. Yield derived from the SORGF model is higher for both prices, and additional water used by the SORGF model is highly significant at the 1 percent level. The SORGF model generates the same yield and water usage under both scenarios because the irrigation decision is not a function of market price.

The DP model's average net revenue exceeds its counterpart for the SORGF model by \$6.16 and \$3.83 for the low and high market prices respectively. The variability, in both absolute and relative terms, of net revenue is lower for irrigations scheduled with DP while the SORGF model even experiences a negative net revenue when sorghum is priced at \$3.80 per cwt.

As in all the comparisons of the DP to the SORGF scenarios, a significant difference in terms of higher pre-emergence and Stage 1 irrigations occur when scheduling by a critical soil moisture ratio.

TABLE XII

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER ALTERNATIVE MARKET PRICES FOR THE DYNAMIC PROGRAMMING AND SORGF IRRIGATION SCHEDULING MODELS

	PGS1 DP SORGHUM PRICE = $3.80				PGS1 SF SORGHUM PRICE = $3.80				PGS2 DP SORGHUM PRICE = $5.00				PGS2 SF SORGHUM PRICE = $5 00			
YEAR	YIELD CWT/ACRE	TOTAL REVENUE $/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	TOTAL REVENUE $/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	TOTAL REVENUE $/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	TOTAL REVENUE $/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE
1	55.76	211.89	9.10	43.31	60.00	228.00	16.80	27.39	57.84	289.21	10.50	114.80	60.00	300.01	16 80	99 39
2	52.79	200.60	8.40	34.92	55.88	212.34	16.80	11.73	52.76	263.79	9.10	95.21	55.88	279.40	16.80	78 78
3	59.30	225.34	7.70	62.58	62.02	235.67	10.50	61.26	59.30	296.49	7.70	133.73	62.02	310.09	10.50	135.68[a]
4	54.50	207.08	11.20	29.76	60.94	231.57	18.90	22.22	58.79	293.93	13.30	107.88	60.94	304.70	18.90	95.34
5	58.52	222.38	5.60	68 36	60.97	231.67	8.40	66.00	59.16	295.79	6.30	138.85	60.97	304.83	8.40	139.16[a]
6	62.54	237.66	4.90	86.55	64.22	244.03	8.40	78.35	61.00	305.00	4.90	153.88	64.22	321.09	8.40	155.41[a]
7	59.51	226.12	9.80	54.62	65.85	250.24	14.70	58.36[a]	61.50	307.51	10.50	133.10	65.85	329.26	14.70	137.38[a]
8	58.83	223.55	7.70	60.79	64.52	245.16	12.60	62.02	61.03	305.16	9.10	136.57	64.52	322.58	12.60	139.44[a]
9	51.74	196.63	2.80	54.25	55.07	209.28	6.30	52.34	53.31	266.56	4.20	118.36	55.07	275.37	6.30	118 43[a]
10	54.48	207.03	0.00	76 30	55.43	210.64	2.10	71.17	54.48	272.41	0.00	141.68	55.43	277.16	2.10	137 69
11	52.17	198.23	9.10	29.64	55.93	212.55	14.70	20.67	51.52	257.61	8.40	91.93	55 93	279.67	14.70	87.79
12	48.79	185.38	1.40	48.83	52.56	199.75	6.30	42.81	51.19	255.94	2.80	113.56	52.56	262.82	6.30	105.88
13	52.37	199.01	4.20	50.81	54.59	207.45	6.30	50 51	52.73	263.63	4.20	115.43	54.59	272.96	6.30	116.02[a]
14	49.98	189.91	4 20	41.71	51.80	196.84	8.40	31.16	51.17	255.85	5.60	101.82	51.80	259.00	8.40	93.32
15	47.32	179.83	2 80	37.46	50.17	190.64	6.30	33.70	46.64	233.19	2.80	90.82	50.17	250.84	6.30	93 90[a]
16	47.38	180.04	1.40	43.49	52.74	200.40	4.20	52.20[a]	51.20	256.02	2.10	116.56	52.74	263.69	4.20	115.49
17	48.07	182.67	9.10	14.09	49.78	189.18	16.80	-11.44	48.07	240.36	9.10	71.77	49.78	248.92	16.80	48.30
18	57.13	217.11	10.50	42.70	63.37	240.81	18.90	31.45	61.80	308.98	12.60	125.84	63.37	316.85	18.90	107 49
19	67.31	255.77	7.70	93.01	70.99	269.77	12.60	86.62	64.62	323.09	7.00	163 24	70.99	354.96	12.60	171.82[a]
20	49 59	188.45	0.00	57.72	49.73	188.96	2.10	49.49	49.59	247.96	0 00	117.23	49.73	248.63	2.10	109.16
21	59.33	225.44	6.30	68.51	62.45	237.30	8 40	71.62[a]	59.33	296 64	6.30	139 70	62.45	312.23	8.40	146.56[a]
22	51.20	194.57	3.50	49.28	52.05	197 80	8.40	32.13	51 44	257 19	4 90	106 08	52 05	260 26	8.40	94 59
23	61.04	231.95	6 30	75 01	64.68	245.80	8.40	80.13[a]	59.76	298.79	5.60	144.76	64.68	323.42	8 40	157 75[a]

[a] Indicates the scenario with the maximum net revenue when it is not the DP model scenario.

TABLE XIII

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER ALTERNATIVE MARKET PRICES FOR THE DYNAMIC PROGRAMMING AND SORGF IRRIGATION SCHEDULING MODELS

		PGS1 DP SORGHUM PRICE = $3.80				PGS1 SF SORGHUM PRICE = $3.80				PGS2 DP SORGHUM PRICE = $5.00				PGS2 SF SORGHUM PRICE = $5.00			
	UNITS	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
YIELD	CWT/AC	54.77	5.38	47.32	67.31	58.08	6.05	49.73	70.99	55.58	5.11	46.64	64.62	58 08	6.05	49.73	70 99
TOTAL REVENUE	$/AC	208.11	20.44	179.83	255.77	220.69	23.00	188.96	269.77	277.87	25.54	233.19	323.09	290.38	30.27	248.63	354 96
WATER PUMPED	INCHES	5.81	3.39	0.00	11.20	**10.32	5.14	2.10	18.90	6.39	3.63	0.00	13.30	**10.32	5.14	2.10	18 90
NET REVENUE	$/AC	53.20	19.11	14.09	93.01	47.04	24.40	-11.44	86 62	120.56	22.23	71.77	163.24	116.73	29 30	48 30	171 82
PRE-EMERGE	INCHES	0.18	0 48	0 00	1.40	**1.73	1 75	0.00	4.20	0 18	0.48	0 00	1.40	**1.73	1.75	0.00	4.20
STAGE 1	INCHES	0.00	0.00	0.00	0.00	**2.19	1.95	0.00	6.30	0.27	0.62	0.00	2.10	**2.19	1.95	0.00	6.30
STAGE 2	INCHES	2.07	1.78	0.00	4.90	2.01	1.73	0.00	6.30	2.13	1.92	0.00	6.30	2.01	1 73	0.00	6.30
STAGE 3	INCHES	1.80	1.62	0.00	5.60	2.01	1.34	0.00	4.20	1.92	1 53	0.00	5.60	2.01	1.34	0.00	4.20
STAGE 4	INCHES	1.77	1.28	0.00	3.50	2.37	1.59	0.00	4.20	1 89	1.34	0.00	4.20	2 37	1.59	0.00	4.20
1 4" IRRIG	#	2.09	1.12	0.00	4.00	**0.00	0.00	0 00	0.00	2 52	1.41	0.00	5.00	**0.00	0.00	0.00	0.00
2.1" IRRIG	#	0.74	0.69	0.00	2.00	**4.91	2.45	1.00	9.00	0.61	0.72	0.00	3 00	**4.91	2.45	1.00	9 00
2.8" IRRIG	#	0.48	0.59	0.00	2.00	**0.00	0.00	0.00	0.00	0.57	0 73	0.00	2.00	**0.00	0.00	0.00	0.00

*Indicates a significant difference at 5 percent with the base scenario.
**Indicates a significant difference at 1 percent with the base scenario.

Results From the DP and SORGF Irrigation Scheduling Models With Alternate Irrigation Variable Costs

Like output prices, the cost of inputs also affects the irrigation decision. In the Oklahoma Panhandle rising natural gas prices are having a great impact on the profitability of irrigated grain sorghum. Changes in the cost of natural gas affect the irrigation decision through positive movements in the variable cost of irrigating. For a typical central pivot irrigation system in the Oklahoma Panhandle using natural gas prices of $2.60, $3.80 and $5.00 per MCF, irrigation variable costs are computed from the Oklahoma State Irrigation Cost Generator at $3.40, $4.16 and $4.92 per acre-inch, respectively. These values are used to analyze the impact of changes in the price of inputs on the irrigation decision.

The 23 years of simulated grain sorghum values for the DP and SORGF scheduling models under two alternative irrigation variable costs are shown in Table XIV. The DP model yields maximum net revenue in 16 of the 23 years with both variable costs. In the SORGF model, a soil moisture irrigation decision is not affected by the price of water. Thus, the SORGF model again derives the same yields for each year under the two cost scenario. The only component of the net revenue equation that changes in the SORGF results is the irrigation cost on a per acre basis. With the DP irrigation scheduling model, irrigations are reduced by 1.04 inches for the higher variable cost.

Table XV reveals that the greater quantity of water pumped is highly significant for the SORGF model. The larger quantity of water

TABLE XIV

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER ALTERNATIVE IRRIGATION VARIABLE COSTS FOR THE DYNAMIC PROGRAMMING AND SORGF IRRIGATION SCHEDULING MODELS

	----------IVC1 DP----------- IRRIG VAR COST = $3.40				----------IVC1 SF----------- IRRIG VAR COST = $3.40				----------IVC2 DP----------- IRRIG VAR COST = $4.92				----------IVC2 SF----------- IRRIG VAR COST = $4.92			
YEAR	YIELD CWT/ACRE	WATER PUMPED INCHES	IRRIG COST $/ACRE	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	IRRIG COST $/ACRE	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	IRRIG COST $/ACRE	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	IRRIG COST $/ACRE	NET REVENUE $/ACRE
1	57.95	10.50	35.70	88.54	60.00	16.80	57.12	76.16	55.76	9.10	44.77	69.85	60 00	16.80	82.66	50.62
2	53.77	9.10	30.94	74.93	55.88	16.80	57.12	58.02	52.37	7.00	34.44	65.24	55.88	16.80	82.66	32 48
3	59.30	7.70	26.18	104.00	62.02	10.50	35.70	106 45[a]	56.85	7.00	34.44	84.96	62.02	10.50	51.66	90.49[a]
4	59.66	14.00	47.60	84.17	60.94	18.90	64.26	73.15	54.50	11.20	55.10	53.95	60.94	18.90	92.99	44.42
5	59.76	6.30	21.42	110.77	60.97	8.40	28.56	108.96	57.52	4.90	24.11	98 26	60 97	8.40	41.33	96.20
6	61.53	4.90	16.66	123.33	64.22	8.40	28.56	123.27	62.54	4.90	24.11	120.35	64.22	8.40	41.33	110.50
7	61.11	10.50	35.70	102.47	65.85	14.70	49.98	109.04[a]	59.51	9 80	48.22	82 88	65.85	14.70	72.32	86.70[a]
8	61.96	9.10	30.94	110.95	64.52	12.60	42.84	110.30	61.92	8.40	41.33	100.40	64.52	12.60	61.99	91.15
9	53.31	4.20	14.28	89.56	55.07	6.30	21.42	90.17[a]	50.76	2.10	10.33	82.30	55.07	6.30	31.00	80 60
10	54.48	0.00	0.00	108 99	55.43	2.10	7.14	106.03	54.48	0.00	0.00	108.99	55.43	2.10	10.33	102.84
11	51.78	8.40	28.56	68.55	55.93	14.70	49.98	65.40	53.71	9.10	44.77	60.84	55.25	14.70	72.32	40 04
12	51.19	2.80	9.52	84.98	52.56	6.30	21.42	79.13	48.79	1.40	6.89	77.04	52.56	6.30	31 00	69 56
13	52.82	4.20	14.28	87.40	54.59	6.30	21.42	88.06	50.39	4 20	20.66	70.31	54.59	6.30	31.00	78.48[a]
14	51.17	5.60	19.04	75.38	51.80	8.40	28.56	68.63	49.98	4 20	20.66	68.51	51.80	8.40	41.33	55.86
15	48.35	4.20	14.28	67.75	50.17	6.30	21.42	68.59[a]	47.32	2.80	13.78	63.72	50.17	6.30	31.00	59.02
16	51.81	2.80	9.52	87.70	52.74	4 20	14.28	87.04	47.38	1.40	6.89	70.85	52 74	4.20	20.66	80 65[a]
17	48.68	9.80	33.32	50.13	49.78	16.80	57.12	31.20	48.07	9.10	44.77	36.01	49 78	16.80	82.66	5.66
18	62.32	13.30	45.22	98.27	63.37	18.90	64.26	83.84	60 16	11 20	55.10	78.87	63.37	18.90	92.99	55.11
19	64.68	7.00	23.80	130.06	70.99	12.60	42.84	138.80[a]	63.18	6 30	31.00	116.25	70.99	12.60	61.99	119 64[a]
20	49.62	1.40	4.76	82 86	49.73	2.10	7.14	80.92	49 59	0.00	0 00	87 47	49.73	2.10	10 33	77.73
21	59.33	6.30	21 42	108 89	62 45	8.40	28 56	115.48[a]	59 33	6 30	31 00	99.31	62 45	8.40	41.33	102.71[a]
22	51.44	4.90	16 66	78 94	52 05	8 40	28 56	69 74	51 20	3 50	17 22	77 34	52 05	8 40	41.33	56 97
23	61 30	6.30	21 42	117.57	64 68	8.40	28 56	125.32[a]	57 20	5 60	27 55	93 39	64 68	8 40	41.33	112.56[a]

[a]Indicates the scenario with the maximum net revenue when it is not the DP model scenario.

TABLE XV

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER ALTERNATIVE IRRIGATION VARIABLE COSTS FOR THE DYNAMIC PROGRAMMING AND SORGF IRRIGATION SCHEDULING MODELS

		IVC1 DP IRRIG VAR COST = $3.40				IVC1 SF IRRIG VAR COST = $3.40				IVC2 DP IRRIG VAR COST = $4.92				IVC2 SF IRRIG VAR COST = $4.92			
	UNITS	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
YIELD	CWT/AC	55.97	5.09	48.35	64.68	58.08	6.05	49 73	70.99	54.46	5.08	47.32	63.18	58.05	6.07	49 73	70.99
WATER PUMPED	INCHES	6.67	3.57	0.00	14 00	**10.32	5.14	2.10	18.90	5.63	3.42	0.00	11.20	**10.32	5.14	2.10	18.90
IRRIG COST	$/AC	22.66	12.15	0.00	47.60	35.08	17.48	7.14	64.26	27.70	16.82	0.00	55.10	**50.76	25.29	10.33	92.99
NET REVENUE	$/AC	92.88	19.69	50.13	130.06	89.73	25.39	31.20	138.80	81.18	20.27	36.01	120.35	73 91	28.67	5.66	119.64
PRE-EMERGE	INCHES	0.18	0.48	0.00	1.40	**1.73	1.75	0.00	4.20	0.18	0.48	0.00	1.40	**1.73	1.75	0.00	4.20
STAGE 1	INCHES	0.33	0.79	0.00	2.80	**2.19	1.95	0.00	6.30	0.00	0.00	0.00	0.00	**2.19	1.95	0.00	6.30
STAGE 2	INCHES	2.16	1.94	0.00	6.30	2.01	1.73	0.00	6.30	2.01	1.81	0.00	4.90	2 01	1.73	0.00	6.30
STAGE 3	INCHES	1.89	1.48	0.00	5.60	2.01	1.34	0.00	4.20	1.64	1.66	0.00	5.60	2 01	1.34	0.00	4.20
STAGE 4	INCHES	2.10	1.33	0.00	4.20	2.37	1.59	0.00	4.20	1.80	1.52	0.00	4.90	2 37	1.59	0.00	4.20
1.4" IRRIG	#	2.52	1.24	0.00	5 00	**0.00	0.00	0.00	0.00	2.00	1.21	0.00	4 00	**0.00	0 00	0.00	0.00
2.1" IRRIG	#	0.57	0.59	0.00	2.00	**4.91	2.45	1.00	9.00	0.65	0.71	0.00	2 00	**4 91	2.45	1.00	9 00
2.8" IRRIG	#	0.70	0.88	0.00	3.00	**0 00	0.00	0.00	0.00	0.52	0.67	0.00	2.00	**0.00	0.00	0.00	0 00

*Indicates a significant difference at 5 percent with the base scenario.
**Indicates a significant difference at 1 percent with the base scenario.

pumped results in the DP's net revenue advantage increasing from $3.15 per acre, with the lower variable cost, to $7.27 per acre when the cost of water is $4.92 per acre-inch. Once more the absolute and relative variance of returns is lower for the DP scheduling model's scenarios.

Results From the DP and SORGF Irrigation Scheduling Models With Alternate Irrigation Application Efficiencies

The final irrigation parameter evaluated in this segment of the results is the application efficiency of the irrigation system. Irrigation system application efficiency can vary over time as the system ages, between different localities due to climatic conditions such as wind, humidity, and temperature affecting evaporation, among different soil types, as well as distinct types of irrigation systems (low pressure versus high pressure). Although application efficiency is not a state variable in the DP model, as are price of grain sorghum and irrigation variable cost, a lower efficiency indirectly impacts the recursion equation either through the revenue side, by reducing the yield for a given application quantity, and/or through the cost side, by requiring a larger application.

Table XVI shows the DP scheduling model deriving the optimal irrigation policy in 16 of 23 years, when the central pivot's application efficiency is 60 percent, and the sorghum price and irrigation variable cost are held constant at $4.40 per cwt and $4.16

TABLE XVI

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER ALTERNATIVE IRRIGATION APPLICATION EFFICIENCIES FOR THE DYNAMIC PROGRAMMING AND SORGF IRRIGATION SCHEDULING MODELS

	IEF1 DP IRRIG EFFICIENCY = 0.60				IEF1 SF IRRIG EFFICIENCY = 0.60				IEF2 DP IRRIG EFFICIENCY = 0.90				IEF2 SF IRRIG EFFICIENCY = 0.90			
YEAR	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE
1	55.91	11.90	7.14	65.76	59.85	21.00	12.60	45.26	58.30	9.10	8.19	87.93	60.26	14.70	13.23	73.25
2	51.79	8.40	5.04	62.22	55.82	21.00	12.60	27.51	53.83	7.70	6.93	74.10	55.89	12.60	11.34	62.79
3	58.41	9.10	5.46	88.42	61.88	12.60	7.56	89.11[a]	60.59	7.00	6.30	106 73	62.32	8.40	7.56	108.54[a]
4	51.86	13.30	7.98	42.14	60.75	25.20	15.12	31.73	59.81	11.90	10.71	82.94	61.34	16.80	15.12	69.26
5	52.79	4.90	2.94	81.16	60.93	10.50	6.30	93.67[a]	59.55	4.90	4 41	110.91	61.09	8.40	7.56	103.13
6	62.39	6.30	3.78	117.57	64.31	8.40	5.04	117.27	61.54	3.50	3.15	125.50	64.58	6.30	5.67	127.23[a]
7	58.40	11.90	7.14	76.72	65.61	18.90	11.34	79.32[a]	62.14	9.10	8.19	104.83	65 95	12.60	11.34	107.03[a]
8	60.25	9.80	5 88	93.62	64.32	14.70	8.82	91.14	61.11	7.70	6.93	106.11	64.58	10.50	9.45	109.74[a]
9	52.63	4.20	2.52	83.37	54.15	8.40	5.04	72.61	52.87	2.80	2.52	90.25	54.28	6.30	5.67	81.91
10	54.48	0.00	0.00	108.99	55.37	2.10	1.26	104.16	54 48	0.00	0.00	108.99	55 47	2 10	1.89	104.60
11	50 42	9.80	5.88	50.35	55.74	18.90	11.34	35.90	52.74	7.70	6.93	69.29	55 94	12.60	11.34	62 98
12	49.47	2.10	1.26	78.22	52.34	6 30	3.78	73.35	51.66	2.80	2.52	84.91	52.36	4.20	3.78	82 20
13	50.11	4.20	2.52	72.27	53.93	8.40	5.04	71.61	52.09	4.20	3.78	81.00	54.77	6.30	5.67	84.03[a]
14	49.65	4.90	2.94	67.36	51.79	10.50	6.30	53.48	51.26	4.90	4.41	74.42	51.65	6.30	5.67	70.31[a]
15	45.49	2.80	1.68	57.79	50.74	6.30	3.78	66.31[a]	48.70	2.80	2.52	71.88	50.77	4.20	3 78	75 16[a]
16	47.06	1.40	0.84	70.53	52.52	6.30	3.78	74.15[a]	51.62	2.10	1.89	87.65	52.76	4.20	3.78	83.96
17	46.13	9.80	5.88	31.49	49.83	18.90	11.34	9.90	48.94	8.40	7.56	49.65	49.91	12 60	11 34	36.47
18	54.35	11.90	7.14	58.93	63.79	25.20	15.12	45.10	62.43	11.20	10.08	97.38	63.93	16.80	15 12	80.67
19	64.53	8.40	5.04	118.27	70.42	16.80	10.08	109.24	68.77	7.00	6.30	142.74	71.26	10.50	9 45	139.12
20	49 59	0 00	0.00	87.47	49.72	2.10	1.26	79.29	49.59	0.00	0.00	87 47	49.73	2.10	1 89	79 35
21	56.90	7.00	4 20	90.52	62.45	10 50	6.30	100.39[a]	60.93	5.60	5.04	114.05	62 61	8.40	7.56	109 80
22	51.13	4.20	2 52	76.78	51.99	10 50	6.30	54.36	51.58	4 20	3.78	78 74	52.08	6.30	5.67	72 22
23	59.57	7.00	4.20	102.27	64 61	10.50	6 30	109 89[a]	60.42	4.90	4 41	114.73	64.71	8 40	7.56	119.07[a]

[a]Indicates the scenario with the maximum net revenue when it is not the DP model scenario.

per acre-inch, respectively. When the irrigation application efficiency is 90 percent, the DP model derives the maximum net revenue in 15 of the 23 years. Irrigation application efficiency does impact on the SORGF model's yield. As the efficiency increases less water is needed to maintain the critical soil moisture level, resulting in higher yields and lower irrigation costs. Likewise yields and water pumping are reduced in the higher efficiency DP scenario as shown in Table XVII.

When irrigation application is only 60 percent efficient, the SORGF model produces significantly higher yields while the DP model's average net revenue exceeds that of the SORGF model by $6.41 per acre. With 90 percent efficient applications, the SORGF model gains only 1.88 cwt per acre and loses $4.75 per acre to the DP model.

Results From the DP Model with Varied Prices, Costs and Irrigation Efficiencies

Results of irrigation schedules derived with the DP model for a grain sorghum price of $3.80, $5.00 and the base case of $4.40 per cwt are reported in Table XVIII. Number of quantities of the DP model scenarios are reported in Appendix D. These data along with the descriptive statistics in Table XIX indicate that the lower price of grain sorghum does reduce the total quantity of irrigation in some years, but it is not a significant reduction at the 5 percent level. The highest price of $5.00/cwt results in a very small change in total irrigation on a yearly basis compared to the base scenario. Results indicate that these changes in grain sorghum price cause a highly

TABLE XVII

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER ALTERNATIVE IRRIGATION APPLICATION EFFICIENCIES FOR THE DYNAMIC PROGRAMMING AND SORGF IRRIGATION SCHEDULING MODELS

		IEF1 DP IRRIG EFFICIENCY = 0.60				IEF1 SF IRRIG EFFICIENCY = 0.60				IEF2 DP IRRIG EFFICIENCY = 0.90				IEF2 SF IRRIG EFFICIENCY = 0.90			
	UNITS	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
YIELD	CWT/AC	53 62	5.18	45.49	64.53	**57.95	6.02	49.72	70.42	56.30	5.48	48.70	68.77	58.18	6.15	49.73	71 26
WATER PUMPED	INCHES	6.67	3.96	0.00	13.30	**12.78	6.79	2.10	25.20	5.63	3.22	0.00	11.90	**8.77	4.32	2.10	16.80
EFFECT WATER	INCHES	4.00	2.38	0.00	7.98	**7.67	4.07	1.26	15.12	5.07	2.90	0.00	10.71	**7.89	3.89	1.89	15.12
NET REVENUE	$/AC	77.49	22.32	31.49	118.27	71.08	29.25	9.90	117 27	93.57	21.03	49.65	142.74	88.82	24.10	36.47	139.12
PRE-EMERGE	INCHES	0.21	0.58	0.00	2.10	**1.83	1.82	0.00	4.20	0.18	0.48	0.00	1.40	**1.64	1.67	0.00	4.20
STAGE 1	INCHES	0.00	0.00	0.00	0.00	**2.74	2.72	0.00	8.40	0.27	0.62	0.00	2.10	**1.64	1.67	0.00	4 20
STAGE 2	INCHES	2.22	1.92	0.00	4.90	2.83	1.86	0.00	6.30	1.95	1 66	0.00	4 90	1.92	1.54	0.00	4.20
STAGE 3	INCHES	1.98	1.74	0.00	5.60	2.28	1.66	0.00	4.20	1.61	1.37	0.00	4.90	1.19	1.06	0.00	2.10
STAGE 4	INCHES	2.25	1.65	0.00	5.60	3.10	2.36	0.00	8.40	1.61	1.27	0.00	3 50	2.37	1.71	0.00	4 20
1.4" IRRIG	#	1.57	1.34	0.00	4.00	**0.00	0.00	0.00	0.00	2 52	1.56	0.00	5.00	**0 00	0.00	0.00	0.00
2.1" IRRIG	#	0.91	1.24	0.00	5.00	**6.09	3.23	1.00	12.00	0 83	0.83	0.00	3.00	**4.17	2.06	1.00	8.00
2.8" IRRIG	#	0.91	0.90	0.00	3.00	**0.00	0.00	0.00	0.00	0.13	0.34	0.00	1.00	0.00	0.00	0.00	0.00

*Indicates a significant difference at 5 percent with the base scenario.
**Indicates a significant difference at 1 percent with the base scenario.

TABLE XVIII

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS MARKET PRICES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL

	BASE DP SORGHUM PRICE = $4.40				PGS1 DP SORGHUM PRICE = $3.80				PGS2 DP SORGHUM PRICE = $5 00			
YEAR	YIELD CWT/ACRE	TOTAL REVENUE $/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	TOTAL REVENUE $/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	TOTAL REVENUE $/ACRE	WATER PUMPED INCHES	NET REVENUE $/ACRE
1	57.26	251.95	10.50	77 54	55.76	211.89	9.10	43.31	57.84	289 21	10.50	114 80
2	52.46	230.84	8 40	65.16	52.79	200.60	8.40	34.92	52.76	263.79	9 10	95 21
3	59.42	261.46	7.70	98.70	59.30	225.34	7.70	62.58	59.30	296.49	7.70	133.73
4	58.79	258.66	13.30	72.60	54.50	207.08	11.20	29.76	58.79	293 93	13 30	107.88
5	59.16	260.30	6.30	103.36	58.52	222.38	5.60	68.36	59.16	295.79	6.30	138.85
6	62.68	275.79	4.90	124.68	62.54	237.66	4.90	86.55	61.00	305.00	4.90	153.88
7	59 51	261.82	9.80	90.32	59.51	226.12	9.80	54.62	61.50	307 51	10.50	133 10
8	61.03	268.54	9.10	99.95	58.83	223.55	7.70	60 79	61.03	305.16	9 10	136 57
9	53.31	234.57	4.20	86.37	51.74	196.63	2.80	54.25	53.31	266.56	4.20	118.36
10	54.48	239.72	0.00	108.99	54.48	207.03	0.00	76.30	54.48	272.41	0.00	141.68
11	53.04	233.37	9.10	64.78	52.17	198.23	9.10	29.64	51.52	257.61	8.40	91 93
12	51.19	225.23	2.80	82.85	48.79	185.38	1.40	48.83	51.19	255.94	2.80	113 56
13	52.37	230.43	4.20	82.23	52.37	199.01	4.20	50.81	52.73	263.63	4 20	115 43
14	49.98	219.90	4.20	71.70	49.98	189.91	4.20	41.71	51.17	255.85	5.60	101.82
15	47.32	208.22	2.80	65.64	47.32	179.83	2 80	37.46	46.64	233 19	2.80	90 82
16	47.38	208.47	1.40	71.82	47.38	180.04	1.40	43.49	51.20	256.02	2.10	116.56
17	48.07	211.52	9.10	42.93	48.07	182.67	9.10	14.09	48.07	240.36	9.10	71.77
18	61.08	268.76	12.60	85.61	57.13	217.11	10.50	42.70	61.80	308.98	12.60	125.84
19	67.32	296.19	7.70	133.43	67.31	255.77	7.70	93.01	64.62	323.09	7.00	163 24
20	49.59	218.20	0.00	87.47	49.59	188.45	0 00	57.72	49 59	247 96	0 00	117 23
21	59 33	261.04	6 30	104.10	59.33	225.44	6.30	68 51	59.33	296.64	6 30	139.70
22	51 46	226.41	4.90	75.30	51.20	194.57	3.50	49.28	51 44	257.19	4.90	106 08
23	61.92	272 44	6 30	115.50	61 04	231.95	6.30	75.01	59 76	298 79	5 60	144 76

TABLE XIX

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS MARKET PRICES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL

		BASE DP SORGHUM PRICE = $4.40				PGS1 DP SORGHUM PRICE = $3.80				PGS2 DP SORGHUM PRICE = $5.00			
		MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
.	UNITS												
YIELD	CWT/AC	55.57	5.59	47.32	67.32	54.77	5.38	47.32	67.31	55.58	5.11	46.64	64.62
TOTAL REVENUE	$/AC	244.51	24.58	208.22	296.19	**208.11	20.44	179.83	255.77	**277.87	25.54	233.19	323.09
WATER PUMPED	INCHES	6.33	3.66	0.00	13.30	5.81	3.39	0.00	11.20	6.39	3.63	0.00	13.30
NET REVENUE	$/AC	87.45	21.36	42.93	133.43	**53.20	19.11	14.09	93.01	**120.56	22.23	71.77	163.24
PRE-EMERGE	INCHES	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40
STAGE 1	INCHES	0.15	0.52	0.00	2.10	0.00	0.00	0.00	0.00	+0.27	0.62	0.00	2.10
STAGE 2	INCHES	2.16	1.89	0.00	6.30	2.07	1.78	0.00	4.90	2.13	1.92	0.00	6.30
STAGE 3	INCHES	1.98	1.66	0.00	5.60	1.80	1.62	0.00	5.60	1.92	1.53	0.00	5.60
STAGE 4	INCHES	1.86	1.31	0.00	3.50	1.77	1.28	0.00	3.50	1.89	1.34	0.00	4.20
1.4" IRRIG	#	2.39	1.23	0.00	5.00	2.09	1.12	0.00	4.00	2.52	1.41	0.00	5.00
2.1" IRRIG	#	0.78	0.80	0.00	3.00	0.74	0.69	0.00	2.00	0.61	0.72	0.00	3.00
2.8" IRRIG	#	0.48	0.67	0.00	2.00	0.48	0.59	0.00	2.00	0.57	0.73	0.00	2.00

*Indicates a significant difference at 5 percent with the base scenario.
**Indicates a significant difference at 1 percent with the base scenario.
+Indicates a significant difference at 5 percent with the second scenario.
++Indicates a significant difference at 1 percent with the second scenario.

significant difference, at the 1 percent level, in revenue and net revenue. Net revenue falls from $87.45 to $53.20 per acre for the lower price. A large increase in revenue and net revenue to $277.87 and $120.56, respectively is also noted for the $5.00/cwt price. Since the only significant changes occur in revenue and net revenue it is asserted that the majority of the impact is due strictly to the multiplicative effect of the change in the price of grain sorghum on the relatively constant yield over the three scenarios.

Statistics on the quantity and number of irrigations during each of five stages pre-emergence through Stage 4 are also reported in Table XIX with the quantities by years given in Appendix C. Changes in the price of grain sorghum result in no significant deviations, at the 1 percent level, in the timing or numbers of irrigations by stages and quantity, respectively.

The values from the DP model for the three irrigation variable costs are reported in Tables XX and XXI. These data indicate that during particular years irrigation applications increase for the cheaper water and decrease when water is more expensive. Net revenue between the scenario with the lowest variable cost of $3.40 per acre-inch and the highest variable cost of $4.92 per acre-inch declines from $93.24 to $81.18 per acre, respectively. This reduction is due to the combined effect of a decrease in yield by 1.51 cwt per acre along with an increase in the cost of water per acre from $23.26 to $27.70.

Note that the increased variable cost results in slight decreases in quantities of water in growth Stages 1 through 4. The least expensive water scenario indicates an increase in water applied, on

TABLE XX

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS IRRIGATION VARIABLE COSTS FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL

	BASE DP VAR IRRIG COST = $4.16				IVC1 DP VAR IRRIG COST = $3.40				IVC2 DP VAR IRRIG COST = $4 92			
YEAR	YIELD CWT/ACRE	WATER PUMPED INCHES	IRRIG COST $/ACRE	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	IRRIG COST $/ACRE	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	IRRIG COST $/ACRE	NET REVENUE $/ACRE
1	57.26	10.50	43.68	77.54	57.95	10.50	35.70	88.54	55 76	9 10	44.77	69 85
2	52.46	8.40	34 94	65.16	53.77	9.10	30.94	74 93	52.37	7 00	34.44	65.24
3	59.42	7.70	32.03	98.70	59.30	7.70	26.18	104.00	56.85	7.00	34.44	84 96
4	58.79	13.30	55.33	72.60	59.66	14.00	47.60	84.17	54 50	11 20	55.10	53 95
5	59.16	6.30	26.21	103.36	59.76	6.30	21.42	110.77	57.52	4.90	24.11	98.26
6	62.68	4.90	20.38	124.68	61.53	4.90	16.66	123.33	62 54	4 90	24.11	120.35
7	59.51	9.80	40.77	90.32	61.11	10.50	35.70	102.47	59.51	9 80	48 22	82.88
8	61.03	9.10	37.86	99.85	61.96	9.10	30.94	110.95	61.92	8.40	41.33	100.40
9	53 31	4.20	17.47	86.37	53.31	4.20	14.28	89.56	50 76	2.10	10.33	82 30
10	54.48	0.00	0.00	108.99	54.48	0.00	0.00	108.99	54.48	0 00	0 00	108.99
11	53.04	9.10	37.86	64.78	51.78	8.40	28.56	68.55	53.71	9.10	44 77	60 84
12	51.19	2.80	11.65	82.85	51.19	2.80	9.52	84.98	48.79	1.40	6 89	77.04
13	52.37	4.20	17.47	82 23	52.82	4.20	14.28	87 40	50.39	4.20	20.66	70 31
14	49.98	4.20	17.47	71.70	51.17	5.60	19.04	75.38	49 98	4 20	20 66	68 51
15	47.32	2.80	11.65	65.84	48.35	4.20	14.28	67.75	47.32	2.80	13 78	63 72
16	47.38	1.40	5.82	71.92	51.81	2.80	9.52	87.70	47.38	1.40	6 89	70 85
17	48 07	9.10	37.86	42.93	48.68	9.80	33.32	50.13	48.07	9 10	44 77	36.01
18	61.08	12.60	52.42	85 61	62.32	13.30	45 22	98 27	60.16	11 20	55 10	78.87
19	67.32	7.70	32.03	133.43	64.68	7.00	23.80	130.06	63.18	6.30	31 00	116 25
20	49.59	0.00	0.00	87.47	49.62	1.40	4.76	82.86	49 59	0 00	0 00	87 47
21	59.33	6.30	26.21	104.10	59.33	6.30	21.42	108 89	59 33	6 30	31 00	99 31
22	51.46	4 90	20.38	75.30	51 44	4.90	16.66	78.94	51 20	3 50	17.22	77 34
23	61 92	6.30	26 21	115 50	61.30	6.30	21 42	117.57	57.20	5.60	27 55	93.39

TABLE XXI

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS COSTS FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL

		BASE DP VAR IRRIG COST = $4.16				IVC1 DP VAR IRRIG COST = $3.40				IVC2 DP VAR IRRIG COST = $4.92			
	UNITS	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
YIELD	CWT/AC	55.57	5.59	47.32	67.32	55.97	5.09	48.35	64.68	54.46	5.08	47.32	63.18
WATER PUMPED	INCHES	6.33	3.66	0.00	13.30	6.67	3.57	0.00	14.00	5.63	3.42	0.00	11.20
IRRIG COST	$/AC	26.33	15.25	0.00	55.33	22.66	12.15	0.00	47.60	27.70	16.82	0.00	55.10
NET REVENUE	$/AC	87.45	21.36	42.93	133.43	92.88	19.69	50.13	130.06	81.18	20.27	36.01	120.35
PRE-EMERGE	INCHES	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40
STAGE 1	INCHES	0.15	0.52	0.00	2.10	0.33	0.79	0.00	2.80	0.00	0.00	0.00	0.00
STAGE 2	INCHES	2.16	1.89	0.00	6.30	2.16	1.94	0.00	6.30	2.01	1.81	0.00	4.90
STAGE 3	INCHES	1.98	1.66	0.00	5.60	1.89	1.48	0.00	5.60	1.64	1.66	0.00	5.60
STAGE 4	INCHES	1.86	1.31	0.00	3.50	2.10	1.33	0.00	4.20	1.80	1.52	0.00	4.90
1.4" IRRIG	#	2.39	1.23	0.00	5.00	2.52	1.24	0.00	5.00	2.00	1.21	0.00	4.00
2.1" IRRIG	#	0.78	0.80	0.00	3.00	0.57	0.59	0.00	2.00	0.65	0.71	0.00	2.00
2.8" IRRIG	#	0.48	0.67	0.00	2.00	0.70	0.88	0.00	3.00	0.52	0.67	0.00	2.00

*Indicates a significant difference at 5 percent with the base scenario.
**Indicates a significant difference at 1 percent with the base scenario.
+Indicates a significant difference at 5 percent with the second scenario.
++Indicates a significant difference at 1 percent with the second scenario.

the average, during Stages 1 and 4 with a reduction in Stage 3. The $3.40 per acre-inch water scenario also results in an increase in the number of 1.4 and 2.8 inch applications and a decrease in 2.1 inch applications while the highest variable cost results in reduced 1.4 inch applications as compared to the other two scenarios.

Reduced application efficiency results in a reduced yield in every year that irrigation water is applied (Table XXII). The inverse is true for the higher application efficiency. Table XXIII shows that the average yield decreases from 55.57 to 53.62 cwt per acre when application efficiency falls from 75 to 60 percent. Yield increases to 56.30 cwt per acre for an efficiency of 90 percent. The higher yields for the higher application efficiencies are achieved with less pumped water, 5.63 versus 6.33 and 6.67, and thus the total cost of water is reduced. This brings about an increase in net revenue through an increase in total revenue and a decrease in cost. The net revenue of $93.57 per acre for the 90 percent efficiency scenario is significantly different, at the 5 percent level, than the net revenue of $77.49 per acre for the 60 percent efficiency scenario.

The decrease in efficiency resulted in no irrigations in Stage 1, while in the highest efficiency scenario, applications increase in Stage 1 and decline in all other stages of growth, as compared to the base case and low efficiency scenarios. There is a significant decrease in 1.4 inch applications along with an increase in 2.8 inch application for the lowest efficiency scenario. The converse is true for the higher efficiency scenario with an increase in 1.4 inch applications and a decrease in 2.8 inch irrigations.

TABLE XXII

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION AND NET REVENUE UNDER VARIOUS IRRIGATION APPLICATION EFFICIENCIES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL

	BASE DP IRRIG EFFICIENCY = 0.75				IEF1 DP IRRIG EFFICIENCY = 0.60				IEF2 DP IRRIG EFFICIENCY = 0.90			
YEAR	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE
1	57.26	10.50	7.87	77.54	55.91	11.90	7.14	65.76	58.30	9.10	8.19	87.93
2	52.46	8.40	6.30	65.16	51.79	8.40	5.04	62.22	53.83	7.70	6.93	74.10
3	59.42	7.70	5.77	98.70	58.41	9.10	5.46	88.42	60.59	7.00	6.30	106.73
4	58.79	13.30	9.97	72.60	51.86	13.30	7.98	42.14	59.81	11.90	10.71	82.94
5	59.16	6.30	4.72	103.36	52.79	4.90	2.94	81.16	59.55	4.90	4.41	110.91
6	62.68	4.90	3.67	124.68	62.39	6.30	3.78	117.57	61.54	3.50	3.15	125.50
7	59.51	9.80	7.35	90.32	58.40	11.90	7.14	76.72	62.14	9.10	8.19	104.83
8	61.03	9.10	6.82	99.95	60.25	9.80	5.88	93.62	61.11	7.70	6.93	106.11
9	53.31	4.20	3.15	86.37	52.63	4.20	2.52	83.37	52.87	2.80	2.52	90.25
10	54.48	0.00	0.00	108.99	54.48	0.00	0.00	108.99	54.48	0.00	0.00	108.99
11	53.04	9.10	6.82	64.78	50.42	9.80	5.88	50.35	52.74	7.70	6.93	69.29
12	51.19	2.80	2.10	82.85	49.47	2.10	1.26	78.22	51.66	2.80	2.52	84.91
13	52.37	4.20	3.15	82.23	50.11	4.20	2.52	72.27	52.09	4.20	3.78	81.00
14	49.98	4.20	3.15	71.70	49.65	4.90	2.94	67.36	51.26	4.90	4.41	74.42
15	47.32	2.80	2.10	65.84	45.49	2.80	1.68	57.79	48.70	2.80	2.52	71.88
16	47.38	1.40	1.05	71.92	47.06	1.40	0.84	70.53	51.62	2.10	1.89	87.65
17	48.07	9.10	6.82	42.93	46.13	9.80	5.88	31.49	48.94	8.40	7.56	49.65
18	61.08	12.60	9.45	85.61	54.35	11.90	7.14	58.93	62.43	11.20	10.08	97.38
19	67.32	7.70	5.77	133.43	64.53	8.40	5.04	118.27	68.77	7.00	6.30	142.74
20	49.59	0.00	0.00	87.47	49.59	0.00	0.00	87.47	49.59	0.00	0.00	87.47
21	59.33	6.30	4.72	104.10	56.90	7.00	4.20	90.52	60.93	5.60	5.04	114.05
22	51.46	4.90	3.67	75.30	51.13	4.20	2.52	76.78	51.58	4.20	3.78	78.74
23	61.92	6.30	4.72	115.50	59.57	7.00	4.20	102.27	60.42	4.90	4.41	114.73

TABLE XXIII

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOU IRRIGATION APPLICATION EFFICIENCIES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL

		BASE DP IRRIG EFFICIENCY = 0.75				IEF1 DP IRRIG EFFICIENCY = 0.60				IEF2 DP IRRIG EFFICIENCY = 0.90			
		MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
.	UNITS												
YIELD	CWT/AC	55.57	5.59	47.32	67.32	53.62	5.18	45.49	64.53	56.30	5.48	48.70	68.77
WATER PUMPED	INCHES	6.33	3.66	0.00	13.30	6.67	3.96	0.00	13.30	5.63	3.22	0.00	11.90
EFFECT WATER	INCHES	4.75	2.75	0.00	9.97	4.00	2.38	0.00	7.98	5.07	2.90	0.00	10.71
NET REVENUE	$/AC	87.45	21.36	42.93	133.43	77.49	22.32	31.49	118.27	+93.57	21.03	49.65	142.74
PRE-EMERGE	INCHES	0.18	0.48	0.00	1.40	0.21	0.58	0.00	2.10	0.18	0.48	0.00	1.40
STAGE 1	INCHES	0.15	0.52	0.00	2.10	0.00	0.00	0.00	0.00	+0.27	0.62	0.00	2.10
STAGE 2	INCHES	2.16	1.89	0.00	6.30	2.22	1.92	0.00	4.90	1.95	1.66	0.00	4.90
STAGE 3	INCHES	1.98	1.66	0.00	5.60	1.98	1.74	0.00	5.60	1.61	1.37	0.00	4.90
STAGE 4	INCHES	1.86	1.31	0.00	3.50	2.25	1.65	0.00	5.60	1.61	1.27	0.00	3.50
1.4" IRRIG	#	2.39	1.23	0.00	5.00	*1.57	1.34	0.00	4.00	2.52	1.56	0.00	5.00
2.1" IRRIG	#	0.78	0.80	0.00	3.00	0.91	1.24	0.00	5.00	0.83	0.83	0.00	3.00
2.8" IRRIG	#	0.48	0.67	0.00	2.00	0.91	0.90	0.00	3.00	*0.13	0.34	0.00	1.00

*Indicates a significant difference at 5 percent with the base scenario.
**Indicates a significant difference at 1 percent with the base scenario.
+Indicates a significant difference at 5 percent with the second scenario.
++Indicates a significant difference at 1 percent with the second scenario.

Results From the DP Model for High Pressure,
Low Pressure and LEPA Irrigation Systems

This final section of results makes use of the DP model to evaluate the performance under three different types of irrigation systems. The price and efficiency assumptions for all the scenarios analyzed in this section are presented in Table XXIV. As before, output from the Oklahoma State University Irrigation Cost Generator is listed in Appendix A and irrigation by inches and numbers are reported in Appendix E for these results.

The high pressure central pivot irrigation system is assumed to have a discharge pressure of 60 psi and relatively inefficient application of 60 percent. Many of the original high pressure systems have been changed to low pressure and most of the new central pivot systems installed these days are low pressure systems. The discharge pressure used for the low pressure system is 30 psi and application efficiency is 75 percent. This is the same for the original base case scenario.

Recently, Low Pressure Precision Application (LEPA) sprinkler systems have received attention on the Texas High Plains. This type of system boasts of far more efficiency than the other two. Discharge pressure and application efficiency for these comparisons are assumed to be 10 psi and 95 percent, respectively. An additional investment in the central pivot system of $6,000 is also included in irrigation cost calculations. This dollar amount is in line with estimates by Ellis, Lacewell and Reneau and Stoecker of $5,000 and $6,952, respectively. Additional management and tillage costs from furrow

TABLE XXIV

PRICES OF GRAIN SORGHUM AND NATURAL GAS, IRRIGATION VARIABLE COST AND IRRIGATION APPLICATION EFFICIENCY FOR FIFTEEN DIFFERENT IRRIGATION SYSTEM SCENARIOS

	Price of Grain Sorghum	Price of Natural Gas	Discharge Pressure (PSI)	Irrigation Variable Cost	Application Efficiency
HPRS	$4.40	$3.80	60	$4.78	.60
LPRS	$4.40	$3.80	30	$4.16	.75
LEPA	$4.40	$3.80	10	$3.93	.95
HPR1	$4.40	$2.60	60	$3.86	.60
LPR1	$4.40	$2.60	30	$3.40	.75
LEP1	$4.40	$2.60	10	$3.28	.95
HPR2	$4.40	$5.00	60	$5.71	.60
LPR2	$4.40	$5.00	30	$4.92	.75
LEP2	$4.40	$5.00	10	$4.58	.95
HPR3	$3.80	$3.80	60	$4.78	.60
LPR3	$3.80	$3.80	30	$4.16	.75
LEP3	$3.80	$3.80	10	$3.93	.95
HPR4	$5.00	$3.80	60	$4.78	.60
LPR4	$5.00	$3.80	30	$4.16	.75
LEP4	$5.00	$3.80	10	$3.93	.95

diking and tilling in a circular fashion are not included but could have significant implications.

In Table XXV, yearly values for the high pressure, low pressure and LEPA irrigation systems are presented. Yield and the quantity of effective water increase as system efficiency increases. The yield increase from the high pressure to the low pressure system is 3.23 cwt/acre as indicated in Table XXVI. Between the low pressure and LEPA systems, yield differs by 1.16 cwt/acre. This is a significant increase, at the 5 percent level, between the low pressure and LEPA systems.

Although the water pumped decreases for the more efficient irrigation systems, the effective water reaching the plant increases over the range of 3.83 inches for the low pressure system to 5.29 for the LEPA system.

Due to a lower yield and higher irrigation cost, the high pressure system receives an average net revenue which is $14.45/acre less than the low pressure system's net revenue and $24.00/acre less than the LEPA system's returns to fixed costs. These differences are significant between the low pressure and high pressure systems and highly significant between the low pressure and LEPA systems.

The major difference in timing and quantities of irrigations occur in Stages 1 and 4. The quantity of water applied in Stage 1 increases as efficiency rises and costs decline, while the reverse is true in Stage 4. Lower cost and higher efficiency also tend to decrease the number of 2.8 inch applications while increasing the number of 1.4 inch irrigations.

TABLE XXV

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENU, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH THE BASE CASE PARAMETERS

	--------1 HPRS DP---------- PSI = 60 EFF = .60				--------2 LPRS DP---------- PSI = 30 EFF = .75				--------3 LEPA DP---------- PSI = 10 EFF = 95			
	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE
YEAR												
1	53.97	9.80	5.88	59.90	57.26	10.50	7.87	77.54	58.42	9.10	8.64	90.55
2	51.63	8.40	5 04	56.30	52.46	8.40	6.30	65.16	54.51	7.70	7.31	78.86
3	57.41	9.10	5.46	78.36	59.42	7.70	5.77	98.70	61.21	7.00	6 65	111.10
4	54.83	14.00	8.40	43.59	58.79	13.30	9 97	72.60	60 04	11 90	11.30	86 69
5	51.31	5.60	3.36	68.28	59.16	6.30	4.72	103.36	58.01	4 20	3 99	108 00
6	59.82	5 60	3.36	105.71	62.68	4.90	3.67	124.68	62.26	3 50	3.32	129 46
7	55.35	9.80	5.88	65.96	59.51	9.80	7.35	90.32	63.45	9.10	8.64	112.68
8	59.77	9.10	5.46	88.77	61.03	9.10	6 82	99.95	62 98	7 70	7.31	116 10
9	50 41	2 80	1.68	77 68	53.31	4 20	3.15	86.37	53.23	2 80	2 66	92.47
10	54.48	0.00	0.00	108.99	54.48	0.00	0.00	108.99	54.48	0 00	0.00	108.99
11	51 20	9.80	5.88	47.69	53.04	9.10	6.82	64.78	53.68	7 70	7.31	75 18
12	50.82	2.80	1.68	79.51	51.19	2.80	2.10	82.85	51.77	2.80	2.66	86 05
13	51.66	4.90	2.94	73.15	52.37	4.20	3.15	82.23	53 75	4 20	3.99	89 27
14	49.65	4.90	2.94	64.33	49.98	4.20	3 15	71.70	51.37	4 90	4.65	76 05
15	45.49	2.80	1 68	56.06	47.32	2.80	2.10	65.84	49.06	2.80	2 66	74 13
16	47.06	1.40	0.84	69 66	47.38	1.40	1.05	71.92	51.72	2 10	1 99	88.58
17	46 20	9.10	5.46	29.06	48.07	9.10	6.82	42 93	48 68	7.70	7.31	53 19
18	56.00	11.90	7 14	58.77	61.08	12.60	9 45	85.61	62 82	11 20	10.64	101 65
19	63 59	7.70	4 62	112.25	67.32	7 70	5.77	133.43	69.63	7 00	6.65	148 13
20	49.59	0.00	0.00	87 47	49 59	0.00	0 00	87.47	49 59	0 00	0 00	87 47
21	56 90	7 00	4 20	86 18	59.33	6.30	4.72	104 10	61 47	5 60	5 32	117 72
22	50 66	3.50	2 10	75 42	51.46	4.90	3.67	75 30	51 64	4 20	3 99	80 00
23	56.86	7.00	4.20	86 01	61 92	6.30	4 72	115 50	61.08	4 90	4.65	118 76

TABLE XXVI

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A GRAIN SORGHUM PRICE OF $3.80

		--------1 HPRS DP---------- PSI = 60 EFF = .60				--------2 LPRS DP---------- PSI = 30 EFF = .75				--------3 LEPA DP---------- PSI = 10 EFF = .95			
	UNITS	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
YIELD	CWT/AC	53.25	4.58	45.49	63.59	55.57	5.59	47.32	67.32	+56.73	5.70	48.68	69.63
TOTAL REVENUE	$/AC	234.28	20.14	200.17	279.79	244.51	24.58	208.22	296.19	+249.62	25.07	214.18	306.37
WATER PUMPED	INCHES	6.39	3.76	0.00	14.00	6.33	3.66	0.00	13.30	5.57	3.21	0.00	11.90
EFFECT WATER	INCHES	3.83	2.26	0.00	8.40	4.75	2.75	0.00	9.97	5.29	3.05	0.00	11.30
IRRIG COST	$/AC	30.55	17.97	0.00	66.92	26.33	15.25	0.00	55.33	21.89	12.62	0.00	46.77
NET REVENUE	$/AC	*73.00	20.60	29.06	112.25	87.45	21.36	42.93	133.43	++97.00	21.48	53.19	148.13
PRE-EMERGE	INCHES	0.21	0.58	0.00	2.10	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40
STAGE 1	INCHES	0.00	0.00	0.00	0.00	0.15	0.52	0.00	2.10	+0.27	0.62	0.00	2.10
STAGE 2	INCHES	1.80	1.91	0.00	4.90	2.16	1.89	0.00	6.30	1.92	1.62	0.00	4.90
STAGE 3	INCHES	2.04	1.46	0.00	5.60	1.98	1.66	0.00	5.60	1.64	1.21	0.00	4.20
STAGE 4	INCHES	2.34	1.52	0.00	4.90	1.86	1.31	0.00	3.50	1.55	1.21	0.00	3.50
1.4" IRRIG	#	*1.52	0.99	0.00	3.00	2.39	1.23	0.00	5.00	**2.65	1.58	0.00	5.00
2.1" IRRIG	#	0.87	0.81	0.00	2.00	0.78	0.80	0.00	3.00	0.83	0.94	0.00	3.00
2.8" IRRIG	#	0.87	0.87	0.00	3.00	0.48	0.67	0.00	2.00	++0.04	0.21	0.00	1.00

*Indicates a significant difference at 5 percent with the second scenario.
**Indicates a significant difference at 1 percent with the second scenario.
+Indicates a significant difference at 5 percent with the first scenario.
++Indicates a significant difference at 1 percent with the first scenario.

Scenario results for the three types of irrigation systems with a grain sorghum price of $3.80 per cwt are presented in Tables XXVII and XXVIII. The lower price has the largest impact on the scheduling of irrigations under the high pressure irrigation systems. The higher variable irrigation cost combined with the lower market price results in less water pumped by the high pressure system than the low pressure system. This along with its lesser efficiency, results in an even greater relative yield reduction than for the previous $4.40 per cwt scenario. The yield of 51.79 cwt per acre for the high pressure system is almost three cwt less than the yield for the low pressure system.

The LEPA systems' yield and irrigation quantities are within 50 pounds and 2 tenths of an inch, respectively of what they were for the $4.40 per cwt grain sorghum. Therefore, almost all the change in net revenue is due to the impact of the lower price on total revenue. This shows that the LEPA system with its lower variable cost and higher efficiency, is affected less by market price changes than the other two systems.

For all three scenarios, the lower market price resulted in lower irrigation applications and in turn reduced irrigation costs which agrees with the marginal analysis theory that a shift in the marginal value product curve downward and to the left brings about a reduced optimal irrigation quantity.

A grain sorghum market price of $5.00 per cwt is used in the next three scenarios as depicted in Tables XXIX and XXX. These scenarios show the inverse of the previous case with the low market price. Yield and irrigation quantities increase very little for the LEPA

TABLE XXVII

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A GRAIN SORGHUM PRICE OF $3.80

	--------1 HPR3 DP---------- SORGHUM PRICE = $3.80				--------2 LPR3 DP---------- SORGHUM PRICE = $3.80				--------3 LEP3 DP---------- SORGHUM PRICE = $3.80			
	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE
YEAR												
1	52.88	9.80	5.88	23.37	55.76	9.10	6.82	43.31	55.59	7.70	7.31	50.24
2	49.94	8.40	5.04	18.89	52.79	8.40	6.30	34.92	54.51	7.70	7.31	46.15
3	56.37	8.40	5.04	43.34	59.30	7.70	5.77	62.58	61.21	7.00	6.65	74.37
4	48.05	11.20	6.72	-1.68	54.50	11.20	8.40	29.76	57.85	10.50	9.97	47.84
5	52.23	4.90	2.94	44.34	58.52	5.60	4.20	68.36	58.35	4.20	3.99	74.49
6	59.77	4.90	2.94	72.97	62.54	4.90	3.67	86.55	62.94	4.20	3.99	91.95
7	56.99	9.80	5.88	39.00	59.51	9.80	7.35	54.62	60.78	8.40	7.98	67.22
8	56.48	9.10	5.46	40.40	58.83	7.70	5.77	60.79	62.54	7.70	7.31	76.66
9	50.27	2.80	1.68	46.90	51.74	2.80	2.10	54.25	53.23	2.80	2.66	60.55
10	54.48	0.00	0.00	76.30	54.48	0.00	0.00	76.30	54.48	0.00	0.00	76.30
11	43.69	7.00	4.20	1.82	52.17	9.10	6.82	29.64	48.40	6.30	5.98	28.45
12	50.07	2.10	1.26	49.51	48.79	1.40	1.05	48.83	51.77	2.80	2.66	54.99
13	50.09	4.20	2.52	39.54	52.37	4.20	3.15	50.81	52.52	4.20	3.99	52.34
14	49.65	4.90	2.94	34.53	49.98	4.20	3.15	41.71	51.37	4.90	4.65	45.22
15	45.20	2.80	1.68	27.65	47.32	2.80	2.10	37.46	49.04	2.80	2.66	44.63
16	47.06	1.40	0.84	41.42	47.38	1.40	1.05	43.49	51.72	2.10	1.99	57.55
17	38.50	5.60	3.36	-11.19	48.07	9.10	6.82	14.09	48.68	7.70	7.31	23.98
18	56.00	11.90	7.14	25.17	57.13	10.50	7.87	42.70	62.29	11.20	10.64	61.94
19	61.23	7.00	4.20	68.49	67.31	7.70	5.77	93.01	69.63	7.00	6.65	106.35
20	49.59	0.00	0.00	57.72	49.59	0.00	0.00	57.72	49.59	0.00	0.00	57.72
21	56.68	7.00	4.20	51.20	59.33	6.30	4.72	68.51	60.78	5.60	5.32	78.22
22	50.54	2.80	1.68	47.92	51.20	3.50	2.62	49.28	51.52	3.50	3.32	51.29
23	55.45	6.30	3.78	49.85	61.04	6.30	4.72	75.01	63.78	5.60	5.32	89.62

TABLE XXVIII

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A GRAIN SORGHUM PRICE OF $3.80

		--------1 HPR3 DP---------- SORGHUM PRICE = $3.80				--------2 LPR3 DP---------- SORGHUM PRICE = $3.80				--------3 LEP3 DP---------- SORGHUM PRICE = $3.80			
	UNITS	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
YIELD	CWT/AC	51.79	5.36	38.50	61.23	54.77	5.38	47.32	67.31	+56.20	5.88	48.40	69.63
TOTAL REVENUE	$/AC	196.81	20.35	146.31	232.68	208.11	20.44	179.83	255.77	+213.56	22.34	183.94	264.59
WATER PUMPED	INCHES	5.75	3.44	0.00	11.90	5.81	3.39	0.00	11.20	5.39	2.97	0.00	11.20
EFFECT WATER	INCHES	3.45	2.06	0.00	7.14	4.36	2.54	0.00	8.40	+5.12	2.82	0.00	10.64
IRRIG COST	$/AC	27.49	16.42	0.00	56 88	24.18	14.12	0.00	46.59	21.17	11.66	0.00	44.02
NET REVENUE	$/AC	*38.59	22.24	-11.19	76.30	53.20	19.11	14.09	93.01	++61.66	19.87	23.98	106.35
PRE-EMERGE	INCHES	0.21	0.58	0.00	2.10	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40
STAGE 1	INCHES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.27	0.62	0.00	2.10
STAGE 2	INCHES	1.31	1.58	0.00	4.90	2.07	1.78	0.00	4.90	1.92	1.58	0.00	4.90
STAGE 3	INCHES	2.16	1.55	0.00	4.90	1.80	1.62	0.00	5.60	1.49	1.29	0.00	4.20
STAGE 4	INCHES	2.07	1.59	0.00	4.90	1.77	1.28	0.00	3.50	1.52	1.21	0.00	3.50
1.4" IRRIG	#	*1.26	0.96	0.00	3.00	2.09	1.12	0.00	4.00	++2.61	1.50	0.00	5.00
2.1" IRRIG	#	0.91	0.85	0.00	2.00	0.74	0.69	0.00	2.00	0.83	0.98	0.00	3.00
2.8" IRRIG	#	0.74	0.81	0.00	2.00	0.48	0.59	0.00	2.00	**0.00	0.00	0.00	0.00

*Indicates a significant difference at 5 percent with the second scenario.
**Indicates a significant difference at 1 percent with the second scenario.
+Indicates a significant difference at 5 percent with the first scenario.
++Indicates a significant difference at 1 percent with the first scenario.

TABLE XXIX

23 YEARS OF SIMULATED GRAIN SORHGUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A GRAIN SORGHUM PRICE OF $5.00

	--------1 HPR4 DP---------- SORGHUM PRICE = $5.00				--------2 LPR4 DP---------- SORGHUM PRICE = $5.00				--------3 LEP4 DP---------- SORGHUM PRICE = $5.00			
	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE
YEAR												
1	55.91	11.90	7.14	91.93	57.84	10.50	7.87	114.80	57.18	8.40	7.98	122 14
2	51.79	8.40	5.04	88.09	52.76	9.10	6.82	95.21	54.51	7.70	7 31	111 57
3	57.41	9.10	5.46	112.80	59.30	7.70	5.77	133.73	61 21	7 00	6 65	147 83
4	51.86	13.30	7.98	65.01	58.79	13.30	9.97	107.88	60.49	11.90	11 30	124 97
5	57.34	6.30	3.78	125.87	59.16	6.30	4.72	138.85	60.04	4.90	4.65	150 21
6	60.01	4.90	2.94	145.91	61.00	4.90	3.67	153.88	62.26	3 50	3.32	166.81
7	58.40	11.90	7.14	104.38	61.50	10.50	7.87	133.10	63.45	9.10	8.64	150.75
8	55.14	8.40	5.04	104.80	61.03	9.10	6.82	136.57	62.18	7 70	7.31	149.91
9	51.68	3.50	2.10	110.92	53.31	4.20	3.15	118.36	53.22	2.80	2.66	124 38
10	54.48	0.00	0.00	141.68	54.48	0.00	0.00	141.68	54.48	0.00	0.00	141.68
11	51.20	9.80	5.88	78.40	51.52	8.40	6.30	91.93	54.12	7.70	7 31	109 61
12	49.47	2.10	1.26	106.60	51.19	2.80	2.10	113.56	51.77	2.80	2.66	117.11
13	50.01	4.20	2.52	99.25	52.73	4.20	3.15	115.43	54.15	4.20	3.99	123.50
14	49.65	4.90	2.94	94 12	51.17	5.60	4.20	101.82	51.45	4.90	4.65	107.26
15	45.49	2.80	1.68	83.35	46.64	2.80	2.10	90.82	49.06	2.80	2.66	103 57
16	47.06	1.40	0.84	87.90	51.20	2.10	1.57	116.56	50.84	1.40	1.33	117.86
17	46.13	9.80	5.88	53.10	48.07	9.10	6.82	71.77	48.68	7.70	7.31	82.39
18	57.09	12.60	7.56	94.48	61.80	12.60	9.45	125.84	63.11	11.20	10.64	140.82
19	61.00	7.00	4.20	140.82	64 62	7.00	5 25	163.24	69.63	7 00	6 65	189 93
20	49 59	0.00	0.00	117.23	49.59	0.00	0.00	117 23	49.59	0 00	0.00	117 23
21	56.90	7.00	4.20	120 32	59.33	6.30	4.72	139.70	61.47	5 60	5.32	154 60
22	51.13	4.20	2.52	104.86	51.44	4.90	3.67	106.08	51.64	4 20	3 99	110 98
23	56.86	7.00	4.20	120 13	59 76	5 60	4.20	144.76	62.44	5 60	5.32	159 47

TABLE XXX

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A GRAIN SORGHUM PRICE OF $5.00

		--------1 HPR4 DP---------- SORGHUM PRICE = $5.00				--------2 LPR4 DP---------- SORGHUM PRICE = $5.00				--------3 LEP4 DP---------- SORGHUM PRICE = $5.00			
		MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
.	UNITS												
YIELD	CWT/AC	53.29	4.45	45.49	61.00	55.58	5.11	46.64	64.62	+56.82	5.79	48.68	69.63
TOTAL REVENUE	$/AC	266.44	22.23	227.47	305.01	277.87	25.54	233.19	323.09	+284.13	28.93	243.38	348.17
WATER PUMPED	INCHES	6.54	3.97	0.00	13.30	6.39	3.63	0.00	13.30	5.57	3.20	0.00	11.90
EFFECT WATER	INCHES	3.93	2.38	0.00	7.98	4.79	2.72	0.00	9.97	5.29	3.04	0.00	11.30
IRRIG COST	$/AC	31.28	18.97	0.00	63.57	26.59	15.09	0.00	55.33	21.89	12.59	0.00	46.77
NET REVENUE	$/AC	*104.43	23.04	53.10	145.91	120.56	22.23	71.77	163.24	++131.51	24.69	82.39	189.93
PRE-EMERGE	INCHES	0.21	0.58	0.00	2.10	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40
STAGE 1	INCHES	0.00	0.00	0.00	0.00	0.27	0.62	0.00	2.10	+0.27	0.62	0.00	2.10
STAGE 2	INCHES	2.22	2.00	0.00	4.90	2.13	1.92	0.00	6.30	1.98	1.72	0.00	5.60
STAGE 3	INCHES	1.98	1.67	0.00	5.60	1.92	1.53	0.00	5.60	1.67	1.31	0.00	4.20
STAGE 4	INCHES	2.13	1.56	0.00	4.90	1.89	1.34	0.00	4.20	1.46	1.21	0.00	3.50
1.4" IRRIG	#	**1.13	1.06	0.00	3.00	2.52	1.41	0.00	5.00	++2.57	1.44	0.00	5.00
2.1" IRRIG	#	1.09	1.24	0.00	5.00	0.61	0.72	0.00	3.00	0.83	0.98	0.00	3.00
2.8" IRRIG	#	0.96	0.93	0.00	3.00	0.57	0.73	0.00	2.00	*0.09	0.29	0.00	1.00

*Indicates a significant difference at 5 percent with the second scenario.
**Indicates a significant difference at 1 percent with the second scenario.
+Indicates a significant difference at 5 percent with the first scenario.
++Indicated a significant difference at 1 percent with the first scenario.

scenario but the largest increases are seen under the low pressure system as compared to the base case of $4.40 per cwt sorghum. Again, there is a significant difference in net revenue between the low pressure and the other two systems. Also, the market price change does not effect the pattern of irrigation quantities by stage.

The next two sets of scenarios analyze the impact of changes in the price of natural gas on irrigation under the three different types of systems. Table XXXI presents the yearly values for the three scenarios with a natural gas price of $2.60 per MCF. The lower variable cost of water brings about larger yearly irrigations and in turn higher yields.

The mean yield for each scenario is approximately 0.5 cwt per acre higher, due to this lower natural gas price, as shown in Table XXXII. Net revenue differs significantly between the high pressure and the other two types of systems. The lower cost of natural gas also produces a slightly higher number of 1.4 and 2.8 inch irrigations than the base cases with $3.80 natural gas.

Results from the scenarios with a natural gas price of $5.00 per MCF are depicted in Tables XXXIII and XXXIV. These figures indicate lower yields and reduced irrigation quantities due to the increases in the cost of water.

Yields for the high pressure, low pressure and LEPA scenarios are 52.03, 54.46 and 55.98 cwt per acre, respectively. Again, as compared to the base scenarios, the mean irrigation quantity declines more for the lower efficiency high cost irrigation system. These reductions in irrigation water are 0.7, 0.7 and 0.3 inches for the high pressure, low pressure and LEPA systems, respectively. This reduction in the

TABLE XXXI

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A NATURAL GAS PRICE OF $2.60

	---------1 HPR1 DP---------- IRRIG VAR COST = 3.86				---------2 LPR1 DP---------- IRRIG VAR COST = 3.40				---------3 LEP1 DP---------- IRRIG VAR COST = 3.28			
YEAR	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE
1	55.13	11.20	6.72	68.59	57.95	10.50	7.87	88.54	59 25	9.80	9 31	97.81
2	52.04	9.80	5.88	60.42	53.77	9.10	6 82	74 93	55 00	8.40	7.98	83.71
3	58 41	9.10	5.46	91.15	59.30	7.70	5.77	104.00	60.28	6 30	5 98	113 84
4	48.06	12 60	7.56	32.10	59 66	14.00	10.50	84.17	60 49	11.90	11 30	96.41
5	58.23	7.00	4.20	98.45	59.76	6.30	4.72	110.77	60.12	5 60	5.32	115.43
6	62.66	6.30	3.78	120.65	61.53	4.90	3.67	123.33	64.04	4.90	4.65	134.96
7	58.40	11.90	7.14	80.29	61.11	10.50	7.87	102.47	64.93	9.10	8.64	125.09
8	59.19	10.50	6.30	89.17	61 96	9.10	6 82	110.95	61.94	7.00	6.65	118 84
9	51.94	4.20	2 52	81.57	53.31	4.20	3.15	89.56	53.22	2 80	2 66	94.27
10	52 31	0 00	0.00	99.44	54.48	0.00	0.00	108.99	54.48	0 00	0.00	108.99
11	50.14	9.80	5.88	52.08	51.78	8.40	6.30	68.55	54.12	7 70	7.31	82.14
12	50.47	2.80	1.68	80.54	51.19	2.80	2.10	84.98	51.77	2 80	2.66	87 87
13	50.11	4.20	2.52	73.53	52.82	4.20	3.15	87.40	54.15	4 20	3.99	93.74
14	50.27	5.60	3:36	68 86	51.17	5.60	4 20	75.38	51 45	4 90	4.65	79.57
15	47 18	4.20	2.52	60 65	48 35	4.20	3.15	67.75	48.37	2.80	2 66	72.92
16	47.06	1.40	0.84	70.95	51.81	2.80	2.10	87.70	52 54	2.80	2.66	91.24
17	46.38	9.80	5 88	35 49	48 68	9.80	7.35	50.13	49 74	9 10	8 64	58 29
18	54.94	11.90	7.14	65.06	62.32	13.30	9.97	98.27	62.90	11.20	10.64	109 31
19	63 82	8.40	5.04	117 64	64 68	7 00	5.25	130.06	69.84	7.00	6.65	153.60
20	49 59	0 00	0 00	87 47	49.62	1.40	1 05	82 86	49.59	0 00	0 00	87 47
21	56.90	7.00	4 20	92.62	59 33	6.30	4.72	108.89	61.47	5 60	5 32	121.36
22	51.12	4.20	2.52	78 00	51 44	4.90	3 67	78 94	51 64	4 20	3.99	82 73
23	59 88	7.00	4.20	105.70	61.30	6.30	4.72	117.57	62.44	5.60	5 32	125 64

TABLE XXXII

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A NATURAL GAS PRICE OF $2.60

		--------1 HPR1 DP---------- IRRIG VAR COST = 3.86				--------2 LPR1 DP---------- IRRIG VAR COST = 3.40				--------3 LEP1 DP---------- IRRIG VAR COST = 3.28			
		MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
	UNITS												
YIELD	CWT/AC	53.66	5.14	46.38	63.82	55.97	5.09	48.35	64.68	+57.12	5.85	48.37	69.84
TOTAL REVENUE	$/AC	236.11	22.60	204.05	280.80	246.27	22.37	212.76	284.59	+251.33	25.74	212.84	307.29
WATER PUMPED	INCHES	6.91	3.81	0.00	12.60	6.67	3.57	0.00	14.00	5.81	3.22	0.00	11.90
EFFECT WATER	INCHES	4.15	2.29	0.00	7.56	5.00	2.68	0.00	10.50	5.52	3.06	0.00	11.30
IRRIG COST	$/AC	26.67	14.72	0.00	48.64	22.66	12.15	0.00	47.60	19.07	10.55	0.00	39.03
NET REVENUE	$/AC	*78.71	22.62	32.10	120.65	92.88	19.69	50.13	130.06	++101.53	22.34	58.29	153.60
PRE-EMERGE	INCHES	0.21	0.58	0.00	2.10	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40
STAGE 1	INCHES	0.00	0.00	0.00	0.00	0.33	0.79	0.00	2.80	0.55	0.89	0.00	2.80
STAGE 2	INCHES	2.25	1.91	0.00	4.90	2.16	1.94	0.00	6.30	1.92	1.64	0.00	5.60
STAGE 3	INCHES	2.22	1.80	0.00	5.60	1.89	1.48	0.00	5.60	1.64	1.03	0.00	3.50
STAGE 4	INCHES	2.22	1.66	0.00	4.90	2.10	1.33	0.00	4.20	1.52	1.11	0.00	2.80
1.4" IRRIG	#	*1.78	1.20	0.00	3.00	2.52	1.24	0.00	5.00	+3.00	1.41	0.00	5.00
2.1" IRRIG	#	0.83	1.23	0.00	4.00	0.57	0.59	0.00	2.00	0.65	0.98	0.00	3.00
2.8" IRRIG	#	0.96	0.98	0.00	3.00	0.70	0.88	0.00	3.00	**0.09	0.29	0.00	1.00

*Indicates a significant difference at 5 percent with the second scenario.
**Indicates a significant difference at 1 percent with the second scenario.
+Indicates a significant difference at 5 percent with the first scenario.
++Indicates a significant difference at 1 percent with the first scenario.

TABLE XXXIII

23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A NATURAL GAS PRICE OF $2.60

	--------1 HPR2 DP---------- IRRIG VAR COST = 5 71				--------2 LPR2 DP---------- IRRIG VAR COST = 4.92				--------3 LEP2 DP---------- IRRIG VAR COST = 4.58			
	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE	YIELD CWT/ACRE	WATER PUMPED INCHES	EFFECT WATER INCHES	NET REVENUE $/ACRE
YEAR												
1	52.92	9.10	5.46	50.16	55.76	9.10	6.82	69.85	55.59	7.70	7.31	78 59
2	48.70	7.70	4.62	39.57	52.37	7.00	5.25	65.24	54.51	7.70	7 31	73.85
3	56.37	8.40	5.04	69.35	56.85	7.00	5.25	84.96	61.02	7.00	6.65	105 70
4	51.44	11.20	6 72	31.66	54.50	11.20	8.40	53.95	57.85	10.50	9.97	75 72
5	52.23	4.90	2.94	71.12	57.52	4.90	3.67	98.26	58.35	4 20	3.99	106.77
6	59.77	4.90	2.94	104.28	62.54	4.90	3.67	120.35	62.94	4.20	3.99	126 99
7	56.99	9.80	5.88	64.08	59.51	9.80	7.35	82.88	60 78	8.40	7.98	98.22
8	55.28	8.40	5.04	64.54	61.92	8.40	6.30	100.40	62 54	7.70	7.31	109.18
9	49.36	2.80	1.68	70.49	50.76	2.10	1.57	82.30	53.23	2 80	2.66	90.67
10	54.48	0.00	0.00	108.99	54.48	0.00	0.00	108.99	54.48	0.00	0.00	108.99
11	43.69	7.00	4.20	21.52	53.71	9.10	6.82	60.84	48.40	6 30	5.98	53 40
12	50.07	2.10	1.26	77.60	48.79	1.40	1.05	77.04	51.77	2.80	2.66	84.23
13	49.90	4.20	2.52	64 83	50.39	4.20	3.15	70.31	52.52	4.20	3.99	81 12
14	49.65	4.90	2.94	59.77	49.98	4.20	3.15	68.51	50.95	4 20	3 99	74.21
15	44.89	2.80	1.68	50.79	47.32	2.80	2.10	63.72	49.04	2.80	2.66	72 23
16	47 06	1.40	0.84	.	47 38	1.40	1.05	70.85	47.69	1.40	1.33	72.69
17	43.38	7.00	4.20	20.19	48.07	9.10	6.82	36.01	48.68	7.70	7.31	48.18
18	56.16	11.90	7.14	48.41	60.16	11.20	8.40	78.87	62.29	11.20	10.64	92.03
19	60.76	7.00	4.20	96.65	63.18	6.30	4.72	116.25	69.63	7.00	6.65	143.58
20	49.59	0 00	0.00	87.47	49.59	0.00	0 00	87.47	49.59	0.00	0.00	87 47
21	57 87	6.30	3.78	87.93	59.33	6 30	4.72	99 31	60.78	5 60	5 32	111 05
22	50.62	2 80	1 68	76.01	51.20	3.50	2.62	77 34	51 52	3 50	3.32	79 93
23	55.45	6 30	3 78	77.26	57.20	5.60	4.20	93.39	63 48	5.60	5.32	122 94

TABLE XXXIV

STATISTICS FOR 23 YEARS OF SIMULATED GRAIN SORGHUM YIELD, REVENUE, IRRIGATION QUANTITIES, AND NET REVENUE UNDER VARIOUS SYSTEM TYPES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH A NATURAL GAS PRICE OF $5.00

		--------1 HPR2 DP---------- IRRIG VAR COST = 5.71				--------2 LPR2 DP---------- IRRIG VAR COST = 4.92				--------3 LEP2 DP---------- IRRIG VAR COST = 4.58			
		MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX	MEAN	STDEV	MIN	MAX
	UNITS												
YIELD	CWT/AC	52.03	4.86	43.38	60.76	54.46	5.08	47.32	63.18	+55.98	6.07	47.69	69.63
TOTAL REVENUE	$/AC	228.92	21.40	190.89	267.35	239.61	22.33	208.23	277.98	+246.33	26.70	209.83	306.37
WATER PUMPED	INCHES	5.69	3.35	0.00	11.90	5.63	3.42	0.00	11.20	5.33	3.01	0.00	11.20
EFFECT WATER	INCHES	3.41	2.01	0.00	7.14	4.22	2.56	0.00	8.40	+5.06	2.86	0.00	10.64
IRRIG COST	$/AC	32.50	19.14	0.00	67.95	27.70	16.82	0.00	55.10	24.39	13.80	0.00	51.30
NET REVENUE	$/AC	*65.70	23.75	20.19	108.99	81.18	20.27	36.01	120.35	++91.21	23.19	48.18	143.58
PRE-EMERGE	INCHES	0.21	0.58	0.00	2.10	0.18	0.48	0.00	1.40	0.18	0.48	0.00	1.40
STAGE 1	INCHES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.27	0.62	0.00	2.10
STAGE 2	INCHES	1.22	1.36	0.00	4.20	2.01	1.81	0.00	4.90	1.89	1.56	0.00	4.90
STAGE 3	INCHES	2.19	1.72	0.00	5.60	1.64	1.66	0.00	5.60	1.49	1.29	0.00	4.20
STAGE 4	INCHES	2.07	1.44	0.00	4.20	1.80	1.52	0.00	4.90	1.49	1.20	0.00	3.50
1.4" IRRIG	#	1.35	0.98	0.00	3.00	2.00	1.21	0.00	4.00	++2.61	1.47	0.00	5.00
2.1" IRRIG	#	0.83	0.78	0.00	2.00	0.65	0.71	0.00	2.00	0.74	1.01	0.00	3.00
2.8" IRRIG	#	0.74	0.75	0.00	2.00	0.52	0.67	0.00	2.00	**0.04	0.21	0.00	1.00

*Indicates a significant difference at 5 percent with the second scenario.
**Indicates a significant difference at 1 percent with the second scenario.
+Indicates a significant difference at 5 percent with the first scenario.
++Indicates a significant difference at 1 percent with the first scenario.

optimal irrigation quantity due to the higher natural gas price, not only confirms the downward sloping nature of the marginal value product curve (diminishing returns), but also that the curve is not as steep for the less efficient systems.

CHAPTER V

SUMMARY AND CONCLUSIONS

The primary objective of this study is to develop an irrigation simulation model which can be used to obtain irrigation schedules which maximize net returns for irrigated grain sorghum in the Oklahoma Panhandle. This objective is achieved by the modification of a grain sorghum plant growth model for use on a microcomputer to schedule irrigations on a day-to-day basis. The model is capable of daily updating and feedback of soil, climatic, irrigation and planting conditions. Net revenue of irrigated grain sorghum is maximized through a dynamic programming recursion algorithm within the model.

Results from the model are tested against scheduling irrigations by a critical soil moisture ratio. Also, optimal irrigation schedules are derived under varying fuel prices, irrigation efficiencies and market prices.

Summary of the DP Irrigation Scheduling Model Versus the SORGF Irrigation Scheduling Model

The DP irrigation scheduling model is compared and contrasted to initiating irrigation under five different critical soil moisture scenarios with the SORGF model. In terms of the highest net revenue, the DP model outperformed the five SORGF scenarios in 14 of 23 years.

Harris's study, using critical soil moisture ratios within the range of 15 to 45 percent, indicated that schedules derived by the

SORGF model were stochastically dominant in the first degree to the contemporary practice of applying 24 inches of water per year. The 24 inch application, as indicated in the previous chapter, appears to maximize yield. Average net revenue from the DP model's irrigation scheduling, over the 23 years, is more than $5.50 higher than any derived by the SORGF scenarios. Also, the absolute and relative variance is lower for the DP model and it uses less water.

Although the DP model's scheduling policy is not optimal in every year, it can be said to be an approximately or near optimal policy. This scheduling model should be preferred for its higher returns to fixed costs as well as its significant water savings.

Summary of the DP and SORGF Irrigation Scheduling Models With Alternative Market Prices, Natural Gas Prices, and Irrigation Application Efficiencies

Upon comparing the DP model to several different SORGF model scenarios, the two scheduling models are examined with various market and natural gas prices, and irrigation application efficiencies. The SORGF model shows no change in the timing of irrigations when market prices or input costs are varied. This insensitivity to input and output prices occurs because irrigations are based solely on the critical soil moisture ratio. The DP model reacts as marginal analysis suggests it should, given a diminishing production function. As the price of the output (grain sorghum) increases the marginal value product curve shifts upward and to the right, resulting in an increase in the optimal irrigation quantity. In terms of input prices, as the marginal factor cost curve moves upward, the optimal water quantity decreases, which is exactly what is observed with the DP scheduling model.

For varied irrigation application efficiencies, the SORGF model does react to these changes as the efficiency directly affects the moisture level in the soil. However, under all of these conditions, the DP model continues to yield the highest mean net revenue with lower relative variation.

Summary of the DP Model With Varied Prices and Irrigation Efficiencies

For changes in the price of grain sorghum for the DP model, yearly irrigation quantities do change in the same direction. However, irrigations are slower to increase than decrease. While total and net revenue differences are highly significant for the varied market prices, alterations on water applications are not significant.

The DP model is able to compensate for the natural gas price increase and decrease so that no significant difference is observed between the three scenarios. Compensation occurs in the form of reducing irrigation applications for the higher cost of water and vice versa for the lower cost. This is true for at least the magnitude of change in natural gas prices analyzed here.

Efficiency of the irrigation system affects not only the water pumped but also has a significant impact on the timing and quantity of each application. As application efficiency increases, more water is applied during Stage 1 of plant growth and number of 1.4 inch applications increase while 2.8 inch applications decrease.

Summary of the DP Model's Evaluation of High Pressure, Low Pressure and LEPA Irrigation Systems

The last section of analysis indicates the impact of market and natural gas prices on optimal irrigation schedules for three different types of irrigation systems. Changes in market price have the greatest affect on the relatively inefficient high pressure system. The high pressure system shows a significant difference in net revenue from the other two types of systems for the three market prices. Very small deviations in optimal irrigations are observed for price fluctuations with the LEPA system.

Natural gas price changes, reflected in the variable cost of irrigation water, affect water applications and net revenue in a similar fashion to varied market prices. The low pressure system receives the largest impact in reduced water applications and lower net revenue. The high efficiency and relatively low cost LEPA system shows very little change in yield and water applications. The LEPA system always generates a highly significant difference in net revenue over the low pressure system. However, the LEPA system incurs higher fixed costs, on a per acre basis, due to the extra investment on the new technology.

Conclusions

The dynamic programming model is said to derive an approximately or near optimal irrigation scheduling policy. Although the model's net revenue values are not maximum in every year, they average only $1.89 per acre per year below the maximum. The next best scheduling model analyzed, averages $7.46 per acre per year below the maximum.

Besides higher returns to fixed costs and lower relative variability of those returns, the DP model achieves substantial water savings. This is an important consideration with the declining water level in the Oklahoma Panhandle.

Simplicity, portability and the updating features of the model, make it available for implementation at the farm level where it can achieve its greatest productivity.

Since this dynamic programming model runs on a microcomputer, its use is restricted only by the availability of such a computer, which are found in most county extension offices as well as on many individual farms. Before the model is implemented at the producer's level, an operator's manual needs to be developed and field testing of the model under controlled conditions at an experiment station is advised.

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APPENDIXES

APPENDIX A

IRRIGATION COST DATA AS CALCULATED BY THE OKLAHOMA STATE UNIVERSITY IRRIGATION COST GENERATOR FOR ALTERNATIVE DISCHARGE PRESSURES AND NATURAL GAS PRICES

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130 0	GALLONS PER MINUTE:	900.	INCHES PER ACRE	14.00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE:	60 00	ACRE INCHES PER YEAR·	1820 00
		TOTAL DYNAMIC HEAD:	388.60	ACRE INCHES PER SET:	2 00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.·	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	6	PIPE DIAMETER·	8.000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER:	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER·	1.690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	3321.00	GEARHEAD COST:	2722.00
PUMP EFFICIENCY:	0 750	STRAINER COST:	61.00	PUMPBASE COST:	1238.00
DRIVE EFFICIENCY:	0.970	SUCTION COST:	106.00	TOTAL PUMP COST:	21591 50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	12375.00	BRAKE HORSEPOWER REQUIRED:	121.40
NAT. GAS FUEL:		FUEL COST PER UNIT:	2 600	WATER HORSEPOWER·	88 32
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED:	210.40
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90 0	PURCHASE HORSEPOWER USED·	225.00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0 00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0.00	DIAMETER:	0.00	DIAMETER:	0 00
COST/FOOT:	3.50	COST/FOOT:	0.00	COST/FOOT:	0.00	COST/FOOT	0.00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	0.00	MAINLINE COST:	0 00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	0.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7.00	TAX RATE:	0.010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON:	0.000
YEARS OF WELL LIFE:	20.	YEARS OF COLUMN LIFE:	16.	TAX ASSESSMENT RATE·	0 200
YEARS OF BOWL LIFE:	8.	YEARS OF GEARHEAD LIFE:	15		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS

	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0.25	0.00	0.00	0.34	0.59	8 24	1071 00	8925 00
PUMP	0.81	0.02	0.06	0.83	1.73	24.18	3143.10	21591 50
MOTOR	0.21	0.01	0.03	0.48	0 73	10.23	1330.33	12375 00
SYSTEMS	1.10	0 03	0.04	1.15	2.33	32.58	4235.00	30000 00
TOTALS	2.36	0.07	0.13	2 80	5.37	75.23	9779.43	72891 50

VARIABLE COSTS

	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0 00	0.00	0.00	0.00	0 00
PUMP	0 00	0.00	0.18	0.00	0.18	2 53	329.29
MOTOR	1.75	0.26	0.40	0.21	2.62	36.72	4774.02
SYSTEMS	0.00	0.00	0.82	0.23	1.05	14.72	1914.05
TOTALS	1 75	0.26	1 41	0.44	3.86	53.98	7017 36
COMPLETE TOTALS					9 23	129.21	16796.79

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130.0	GALLONS PER MINUTE:	900.	INCHES PER ACRE·	14.00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE·	60.00	ACRE INCHES PER YEAR:	1820.00
		TOTAL DYNAMIC HEAD:	388.60	ACRE INCHES PER SET·	2.00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.:	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	6	PIPE DIAMETER:	8.000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER:	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER:	1.690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	3321.00	GEARHEAD COST:	2722.00
PUMP EFFICIENCY:	0.750	STRAINER COST:	61.00	PUMPBASE COST:	1238.00
DRIVE EFFICIENCY:	0.970	SUCTION COST:	106.00	TOTAL PUMP COST:	21591.50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	12375.00	BRAKE HORSEPOWER REQUIRED·	121.40
NAT. GAS FUEL:		FUEL COST PER UNIT:	3.800	WATER HORSEPOWER:	88.32
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED·	210.40
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90.0	PURCHASE HORSEPOWER USED·	225.00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0 00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0.00	DIAMETER:	0.00	DIAMETER·	0 00
COST/FOOT:	3.50	COST/FOOT:	0 00	COST/FOOT:	0.00	COST/FOOT:	0 00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	0.00	MAINLINE COST:	0 00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	0.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7.00	TAX RATE:	0.010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON:	0 000
YEARS OF WELL LIFE:	20.	YEARS OF COLUMN LIFE:	16.	TAX ASSESSMENT RATE:	0.200
YEARS OF BOWL LIFE:	8.	YEARS OF GEARHEAD LIFE:	15.		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0.25	0.00	0.00	0.34	0.59	8.24	1071.00	8925 00
PUMP	0.81	0.02	0.06	0.83	‘1.73	24.18	3143.10	21591 50
MOTOR	0.21	0.01	0.03	0.48	0.73	10.23	1330.33	12375 00
SYSTEMS	1.10	0.03	0.04	1.15	2 33	32 58	4235 00	30000 00
TOTALS	2.36	0.07	0.13	2 80	5.37	75 23	9779.43	72891 50

VARIABLE COSTS	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0.00	0 00	0 00	0.00	0 00
PUMP	0.00	0.00	0.18	0.00	0.18	2.53	329.29
MOTOR	2.55	0.38	0.40	0 21	3.55	49 69	6460 32
SYSTEMS	0.00	0.00	0.82	0.23	1 05	14 72	1914 05
TOTALS	2.55	0.38	1.41	0.44	4 78	66.95	8703.66
COMPLETE TOTALS					10 16	142.18	18483.09

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130.0	GALLONS PER MINUTE:	900.	INCHES PER ACRE:	14.00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE:	60.00	ACRE INCHES PER YEAR:	1820 00
		TOTAL DYNAMIC HEAD:	388.60	ACRE INCHES PER SET:	2 00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.:	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	6	PIPE DIAMETER:	8.000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER:	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER:	1.690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	3321.00	GEARHEAD COST:	2722 00
PUMP EFFICIENCY:	0.750	STRAINER COST:	. 61.00	PUMPBASE COST:	1238.00
DRIVE EFFICIENCY:	0.970	SUCTION COST:	106.00	TOTAL PUMP COST:	21591.50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	12375.00	BRAKE HORSEPOWER REQUIRED:	121.40
NAT. GAS FUEL:		FUEL COST PER UNIT:	5.000	WATER HORSEPOWER:	88.32
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED:	210.40
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90.0	PURCHASE HORSEPOWER USED:	225.00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0 00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0.00	DIAMETER:	0.00	DIAMETER:	0 00
COST/FOOT:	3.50	COST/FOOT:	0.00	COST/FOOT:	0.00	COST/FOOT:	0 00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	' 0.00	MAINLINE COST:	0 00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	0.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7.00	TAX RATE:	0 010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON:	0.000
YEARS OF WELL LIFE:	20.	YEARS OF COLUMN LIFE:	16.	TAX ASSESSMENT RATE·	0.200
YEARS OF BOWL LIFE:	8.	YEARS OF GEARHEAD LIFE:	15.		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0 25	0.00	0.00	0.34	0.59	8 24	1071.00	8925 00
PUMP	0.81	0.02	0.06	0 83	1.73	24.18	3143.10	21591 50
MOTOR	0.21	0.01	0.03	0.48	0.73	10.23	1330.33	12375 00
SYSTEMS	1.10	0.03	0 04	1.15	2.33	32.58	4235.00	30000 00
TOTALS	2.36	0.07	0.13	2.80	5.37	75.23	9779.43	72891 50

VARIABLE COSTS	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0.00	0 00	0.00	0 00	0.00
PUMP	0.00	0 00	0 18	0 00	0.18	2.53	329.29
MOTOR	3.36	0.50	0.40	0.21	4.48	62.67	8146.62
SYSTEMS	0.00	0.00	0 82	0.23	1 05	14 72	1914.05
TOTALS	3.36	0.50	1 41	0 44	5.71	79.92	10389 96
COMPLETE TOTALS					11.08	155 15	20169 39

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130.0	GALLONS PER MINUTE:	900.	INCHES PER ACRE:	14.00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE:	30.00	ACRE INCHES PER YEAR:	1820.00
		TOTAL DYNAMIC HEAD:	319.30	ACRE INCHES PER SET:	2.00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.:	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	5	PIPE DIAMETER:	8.000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER:	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER:	1.690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	2951.00	GEARHEAD COST:	1786.00
PUMP EFFICIENCY:	0.750	STRAINER COST:	61.00	PUMPBASE COST:	1238.00
DRIVE EFFICIENCY:	0.970	SUCTION COST:	106.00	TOTAL PUMP COST:	20285.50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	9625.00	BRAKE HORSEPOWER REQUIRED:	99.75
NAT. GAS FUEL:		FUEL COST PER UNIT:	2.600	WATER HORSEPOWER:	72.57
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED:	172.88
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90.0	PURCHASE HORSEPOWER USED:	175 00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0.00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0.00	DIAMETER:	0.00	DIAMETER:	0.00
COST/FOOT:	3.50	COST/FOOT:	0 00	COST/FOOT:	0.00	COST/FOOT:	0 00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	0.00	MAINLINE COST:	0 00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	0.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7.00	TAX RATE:	0 010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON:	0.000
YEARS OF WELL LIFE:	20.	YEARS OF COLUMN LIFE:	16.	TAX ASSESSMENT RATE:	0.200
YEARS OF BOWL LIFE:	8.	YEARS OF GEARHEAD LIFE:	15.		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS

	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0.25	0.00	0 00	0.34	0.59	8.24	1071.00	8925.00
PUMP	0.75	0.02	0.06	0.78	1.61	22.57	2933.89	20285.50
MOTOR	0.16	0.01	0.03	0.37	0.57	7.96	1034.70	9625 00
SYSTEMS	1.10	0.03	0.04	1.15	2.33	32.58	4235.00	30000 00
TOTALS	2.26	0.07	0.12	2.65	5.10	71.34	9274.59	68835 50

VARIABLE COSTS

	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PUMP	0.00	0.00	0.17	0.00	0.17	2.38	309 37
MOTOR	1.43	0.22	0.31	0.21	2 18	30.45	3958.89
SYSTEMS	0.00	0.00	0.82	0.23	1.05	14.72	1914 05
TOTALS	1.43	0.22	1.31	0.44	3.40	47.56	6182 31
COMPLETE TOTALS					8.49	118.90	15456.90

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130.0	GALLONS PER MINUTE:	900.	INCHES PER ACRE:	14.00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE:	30.00	ACRE INCHES PER YEAR·	1820.00
		TOTAL DYNAMIC HEAD:	319.30	ACRE INCHES PER SET·	2.00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.:	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	5	PIPE DIAMETER:	8 000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER·	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER:	1.690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	2951.00	GEARHEAD COST:	1786.00
PUMP EFFICIENCY:	0.750	STRAINER COST:	61.00	PUMPBASE COST:	1238.00
DRIVE EFFICIENCY:	0.970	SUCTION COST:	106.00	TOTAL PUMP COST:	20285 50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	9625.00	BRAKE HORSEPOWER REQUIRED:	99.75
NAT. GAS FUEL:		FUEL COST PER UNIT:	3.800	WATER HORSEPOWER:	72.57
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED:	172.88
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90.0	PURCHASE HORSEPOWER USED:	175.00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0 00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0.00	DIAMETER:	0.00	DIAMETER:	0 00
COST/FOOT:	3.50	COST/FOOT:	0.00	COST/FOOT:	0.00	COST/FOOT:	0 00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	0.00	MAINLINE COST:	0 00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	0.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7 00	TAX RATE:	0 010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON·	0.000
YEARS OF WELL LIFE:	20.	YEARS OF COLUMN LIFE:	16.	TAX ASSESSMENT RATE·	0.200
YEARS OF BOWL LIFE:	8.	YEARS OF GEARHEAD LIFE:	15.		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS

	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0.25	0.00	0 00	0.34	0.59	8.24	1071 00	8925 00
PUMP	0 75	0.02	0.06	0.78	1.61	22.57	2933.89	20285 50
MOTOR	0.16	0.01	0.03	0.37	0.57	7.96	1034.70	9625 00
SYSTEMS	1 10	0.03	0 04	1.15	2.33	32.58	4235 00	30000 00
TOTALS	2.26	0.07	0.12	2 65	5.10	71.34	9274.59	68835 50

VARIABLE COSTS

	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0 00	0.00	0.00	0.00	0.00
PUMP	0.00	0.00	0.17	0.00	0.17	2.38	309.37
MOTOR	2.10	0.31	0.31	0.21	2.94	41 11	5344.47
SYSTEMS	0 00	0.00	0 82	0.23	1.05	14.72	1914 05
TOTALS	2.10	0.31	1.31	0.44	4.16	58 21	7567.89
COMPLETE TOTALS					9.25	129.56	16842.48

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130.0	GALLONS PER MINUTE:	900.	INCHES PER ACRE:	14.00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE:	30.00	ACRE INCHES PER YEAR:	1820.00
		TOTAL DYNAMIC HEAD:	319.30	ACRE INCHES PER SET:	2 00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.:	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	5	PIPE DIAMETER:	8.000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER:	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER:	1.690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	2951.00	GEARHEAD COST:	1786 00
PUMP EFFICIENCY:	0.750	STRAINER COST:	61.00	PUMPBASE COST:	1238 00
DRIVE EFFICIENCY:	0.970	SUCTION COST:	106.00	TOTAL PUMP COST:	20285.50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	9625.00	BRAKE HORSEPOWER REQUIRED:	99.75
NAT. GAS FUEL:		FUEL COST PER UNIT:	5.000	WATER HORSEPOWER:	72.57
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED:	172.88
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90.0	PURCHASE HORSEPOWER USED:	175 00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0 00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0.00	DIAMETER:	0.00	DIAMETER:	0.00
COST/FOOT:	3.50	COST/FOOT:	0.00	COST/FOOT:	0.00	COST/FOOT:	0 00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	0.00	MAINLINE COST:	0.00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	0.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7.00	TAX RATE:	0.010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON:	0.000
YEARS OF WELL LIFE:	20.	YEARS OF COLUMN LIFE:	16.	TAX ASSESSMENT RATE:	0.200
YEARS OF BOWL LIFE:	8	YEARS OF GEARHEAD LIFE:	15.		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0.25	0.00	0.00	0.34	0.59	8.24	1071.00	8925 00
PUMP	0.75	0.02	0 06	0.78	1 61	22.57	2933.89	20285 50
MOTOR	0.16	0.01	0.03	0.37	0.57	7.96	1034.70	9625.00
SYSTEMS	1.10	0 03	0.04	1.15	2.33	32 58	4235.00	30000.00
TOTALS	2.26	0.07	0.12	2.65	5 10	71.34	9274.59	68835 50

VARIABLE COSTS	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PUMP	0.00	0.00	0.17	0.00	0.17	2.38	309.37
MOTOR	2.76	0.41	0.31	0.21	3.70	51.77	6730.05
SYSTEMS	0 00	0.00	0.82	0.23	1.05	14.72	1914 05
TOTALS	2.76	0.41	1 31	0.44	4.92	68.87	8953.47
COMPLETE TOTALS					10.02	140 22	18228.06

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130.0	GALLONS PER MINUTE:	900.	INCHES PER ACRE:	14 00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE:	10.00	ACRE INCHES PER YEAR:	1820 00
		TOTAL DYNAMIC HEAD:	273.10	ACRE INCHES PER SET:	2.00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.:	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	4	PIPE DIAMETER:	8.000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER:	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER:	1.690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	2581.00	GEARHEAD COST:	1786 00
PUMP EFFICIENCY:	0.750	STRAINER COST:	61.00	PUMPBASE COST:	1238.00
DRIVE EFFICIENCY:	0 970	SUCTION COST:	106.00	TOTAL PUMP COST:	19915.50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	8250.00	BRAKE HORSEPOWER REQUIRED:	85.32
NAT. GAS FUEL:		FUEL COST PER UNIT:	2.600	WATER HORSEPOWER:	62.07
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED:	147.86
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90.0	PURCHASE HORSEPOWER USED:	150.00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0 00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0.00	DIAMETER:	0.00	DIAMETER:	0.00
COST/FOOT:	3.50	COST/FOOT:	0.00	COST/FOOT:	0.00	COST/FOOT:	0 00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	0.00	MAINLINE COST:	0.00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	6000.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7.00	TAX RATE:	0 010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON:	0 000
YEARS OF WELL LIFE:	20	YEARS OF COLUMN LIFE:	16.	TAX ASSESSMENT RATE:	0.200
YEARS OF BOWL LIFE:	8.	YEARS OF GEARHEAD LIFE:	15.		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS

	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0.25	0.00	0.00	0 34	0.59	8 24	1071.00	8925 00
PUMP	0.73	0.02	0.05	0.77	1.57	21 99	2859 15	19915 50
MOTOR	0.14	0.01	0.02	0.32	0.49	6 82	886.89	8250 00
SYSTEMS	1.32	0.04	0.05	1.38	2.79	39 09	5082 00	36000 00
TOTALS	2 43	0.07	0.13	2.81	5.44	76.15	9899.04	73090 50

VARIABLE COSTS

	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0.00	0 00	0.00	0.00	0 00
PUMP	0.00	0.00	0.17	0.00	0 17	2 34	303.73
MOTOR	1.23	0.18	0.27	0.21	1.89	26.48	3442.73
SYSTEMS	0.00	0.00	0.99	0.23	1.22	17.03	2214.05
TOTALS	1 23	0.18	1.43	0.44	3.28	45 85	5960.51
COMPLETE TOTALS					8.71	122.00	15859 55

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130.0	GALLONS PER MINUTE:	900.	INCHES PER ACRE:	14.00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE:	10.00	ACRE INCHES PER YEAR:	1820.00
		TOTAL DYNAMIC HEAD:	273.10	ACRE INCHES PER SET:	2.00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.:	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	4	PIPE DIAMETER:	8.000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER:	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER:	1.690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	2581.00	GEARHEAD COST:	1786.00
PUMP EFFICIENCY:	0.750	STRAINER COST:	61.00	PUMPBASE COST:	1238.00
DRIVE EFFICIENCY:	0.970	SUCTION COST:	106.00	TOTAL PUMP COST:	19915.50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	8250.00	BRAKE HORSEPOWER REQUIRED:	85.32
NAT. GAS FUEL:		FUEL COST PER UNIT:	3.800	WATER HORSEPOWER:	62.07
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED:	147.86
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90.0	PURCHASE HORSEPOWER USED:	150 00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0 00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0.00	DIAMETER:	0.00	DIAMETER:	0 00
COST/FOOT:	3.50	COST/FOOT:	0.00	COST/FOOT:	0.00	COST/FOOT:	0 00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	0.00	MAINLINE COST:	0.00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	6000.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7.00	TAX RATE:	0.010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON:	0.000
YEARS OF WELL LIFE:	20.	YEARS OF COLUMN LIFE:	16.	TAX ASSESSMENT RATE:	0.200
YEARS OF BOWL LIFE:	8.	YEARS OF GEARHEAD LIFE:	15.		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0.25	0.00	0.00	0.34	0.59	8.24	1071.00	8925 00
PUMP	0.73	0.02	0.05	0 77	1.57	21.99	2859.15	19915 50
MOTOR	0.14	0.01	0.02	0.32	0.49	6.82	886.89	8250 00
SYSTEMS	1.32	0.04	0 05	1.38	2.79	39.09	5082.00	36000 00
TOTALS	2.43	0.07	0.13	2.81	5.44	76.15	9899.04	73090 50

VARIABLE COSTS	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PUMP	0 00	0.00	0.17	0.00	0.17	2 34	303 73
MOTOR	1.79	0.27	0.27	0.21	2.54	35.60	4627.83
SYSTEMS	0 00	0.00	0.99	0.23	1.22	17.03	2214.05
TOTALS	1.79	0.27	1.43	0.44	3 93	54.97	7145.61
COMPLETE TOTALS					9.37	131 11	17044 64

SYSTEM REQUIREMENTS CHARACTERISTICS AND COSTS

THE FARM

ACRES COVERED:	130 0	GALLONS PER MINUTE:	900.	INCHES PER ACRE:	14.00
ANNUAL HOURS USE:	915.1	PRESSURE/SQ IN. AT DISCHARGE:	10.00	ACRE INCHES PER YEAR:	1820.00
		TOTAL DYNAMIC HEAD:	273.10	ACRE INCHES PER SET:	2.00

THE WELL

WELL DEPTH:	350.0	DEPTH TO WATER LEVEL:	250.0	COST/FOOT DRILL & DEVLP.:	25.50

THE PUMP

DEPTH SETTING COL. PIPE:	330.	NUMBER OF BOWLS SET:	4	PIPE DIAMETER:	8 000
IF 1,EXTRA 10 FT SECTION:	1	COST PER BOWL:	1101.00	TUBE DIAMETER:	2.500
# OF 20 FT COLUMN SECT.:	16	SECONDARY BOWL COST:	370.00	SHAFT DIAMETER·	1 690
PRICE PER 20 FT SECTION:	829.00	TOTAL COST OF BOWLS:	2581.00	GEARHEAD COST:	1786.00
PUMP EFFICIENCY:	0.750	STRAINER COST:	61.00	PUMPBASE COST:	1238.00
DRIVE EFFICIENCY:	0.970	SUCTION COST:	106.00	TOTAL PUMP COST:	19915.50

THE ENGINE

LIGHT INDUSTRIAL ENGINE		ENGINE COST:	8250.00	BRAKE HORSEPOWER REQUIRED:	85.32
NAT. GAS FUEL:		FUEL COST PER UNIT:	5.000	WATER HORSEPOWER:	62.07
ENGINE HAS RADIATOR AND/OR FAN		ALTITUDE:	3100.	PURCHASE HORSEPOWER NEEDED·	147.86
THERE ARE ENGINE ACCESSARIES		AVERAGE MAXIMUM TEMPERATURE:	90.0	PURCHASE HORSEPOWER USED·	150.00
HOURS OF ENGINE LIFE:	30000.				

THE DISTRIBUTION SYSTEM

SECTION ONE		SECTION TWO		SECTION THREE		SECTION FOUR	
FEET:	1320.00	FEET:	0.00	FEET:	0.00	FEET:	0 00
TYPE PIPE:	PLASTIC	TYPE PIPE:		TYPE PIPE:		TYPE PIPE:	
DIAMETER:	8.00	DIAMETER:	0 00	DIAMETER:	0.00	DIAMETER:	0 00
COST/FOOT:	3.50	COST/FOOT:	0.00	COST/FOOT:	0.00	COST/FOOT:	0 00
NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1.	NUMBER LINES:	1
BELOW GROUND VALVES:	0.	ABOVE GROUND VALVES:	0.	LATERAL PIPE COST:	0.00	MAINLINE COST:	0 00
COST BELOW GR. VALVES:	30.10	COST ABOVE GR. VALVES:	25.75	TOTAL VALVE COST:	0.00	DISTANCE BETWEEN SETS:	1320
COST/FOOT SAFETY LINE:	0.00	COST OF PIVOT:	6000.00	COST SELF PRO.LATERAL:	30000.00		

THE PARAMETERS

INTEREST RATE:	0.140	LABOR COST PER HOUR:	7.00	TAX RATE:	0 010
INSURANCE RATE:	0.005	COST/GAL OIL OR GREASE:	5.00	WELL TAX PER GALLON:	0.000
YEARS OF WELL LIFE:	20	YEARS OF COLUMN LIFE:	16	TAX ASSESSMENT RATE·	0.200
YEARS OF BOWL LIFE:	8.	YEARS OF GEARHEAD LIFE:	15		

THE PER ACRE INCH COST SUMMARY

FIXED COSTS	DEPRECIATION	TAXES	INSURANCE	INTEREST	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR	INVESTMENT COSTS
WELL	0.25	0.00	0.00	0 34	0.59	8.24	1071.00	8925 00
PUMP	0.73	0.02	0 05	0.77	1.57	21.99	2859.15	19915 50
MOTOR	0.14	0.01	0 02	0.32	0.49	6.82	886.89	8250 00
SYSTEMS	1.32	0 04	0.05	1.38	2.79	39 09	5082.00	36000.00
TOTALS	2.43	0.07	0.13	2.81	5.44	76.15	9899.04	73090 50

VARIABLE COSTS	FUEL	LUBRICANTS	REPAIRS	LABOR	TOTAL/ACIN	TOTAL/ACRE	TOTAL/YEAR
WELL	0.00	0.00	0.00	0 00	0.00	0.00	0.00
PUMP	0.00	0.00	0 17	0.00	0.17	2.34	303 73
MOTOR	2.36	0.35	0.27	0 21	3 19	44 71	5812.93
SYSTEMS	0.00	0.00	0.99	0.23	1.22	17 03	2214.05
TOTALS	2.36	0 35	1.43	0 44	4.58	64 08	8330 70
COMPLETE TOTALS					10.02	140 23	18229 73

APPENDIX B

23 YEARS OF SIMULATED GRAIN SORGHUM IRRIGATIONS BY INCHES AND NUMBERS FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING BASE SCENARIO AND THE SORGF IRRIGATION SCHEDULING MODEL WITH VARIOUS CRITICAL SOIL MOISTURE RATIOS

	SCENARIO														
	BASE DP					B15 SF MOISTURE RATIO = 0.15					B20 SF MOISTURE RATIO = 0.20				
YEAR	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	6.30	1.40	2.80	2.10	4.20	4.20	2.10	2.10	2.10	4.20	4.20	2.10	4.20
2	0.00	0.00	4.20	2.80	1.40	2.10	4.20	4.20	2.10	2.10	4.20	4.20	2.10	2.10	2.10
3	0.00	0.00	0.00	4.90	2.80	0.00	0.00	2.10	2.10	4.20	0.00	0.00	4.20	2.10	4.20
4	1.40	2.10	4.20	2.80	2.80	4.20	2.10	4.20	2.10	4.20	4.20	4.20	4.20	2.10	4.20
5	0.00	0.00	1.40	2.10	2.80	0.00	2.10	2.10	0.00	4.20	0.00	2.10	2.10	0.00	4.20
6	0.00	0.00	0.00	2.10	2.80	0.00	0.00	2.10	2.10	2.10	2.10	0.00	0.00	2.10	2.10
7	0.00	0.00	4.20	2.10	3.50	0.00	2.10	4.20	2.10	4.20	2.10	2.10	4.20	2.10	4.20
8	0.00	0.00	4.20	1.40	3.50	0.00	0.00	6.30	0.00	4.20	0.00	2.10	4.20	2.10	4.20
9	0.00	0.00	2.80	0.00	1.40	0.00	2.10	2.10	0.00	0.00	2.10	0.00	4.20	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	4.20	2.10	2.80	2.10	2.10	2.10	4.20	2.10	2.10	4.20	2.10	2.10	2.10
12	0.00	0.00	1.40	1.40	0.00	0.00	2.10	2.10	0.00	0.00	0.00	4.20	2.10	0.00	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	0.00	2.10	2.10	0.00	0.00	2.10	2.10	2.10
14	0.00	0.00	2.80	1.40	0.00	0.00	2.10	2.10	2.10	0.00	0.00	4.20	2.10	2.10	0.00
15	1.40	0.00	0.00	0.00	1.40	2.10	0.00	2.10	0.00	0.00	4.20	0.00	0.00	0.00	2.10
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	4.20	0.00	0.00	0.00	2.10	2.10
17	0.00	0.00	3.50	5.60	0.00	2.10	4.20	4.20	2.10	2.10	4.20	2.10	4.20	4.20	0.00
18	1.40	0.00	2.80	5.60	2.80	4.20	4.20	2.10	4.20	2.10	4.20	4.20	4.20	2.10	4.20
19	0.00	1.40	0.00	3.50	2.80	2.10	2.10	2.10	0.00	4.20	2.10	2.10	2.10	0.00	6.30
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00
21	0.00	0.00	1.40	1.40	3.50	0.00	0.00	2.10	2.10	4.20	0.00	2.10	0.00	2.10	4.20
22	0.00	0.00	3.50	1.40	0.00	0.00	2.10	4.20	0.00	0.00	0.00	2.10	4.20	0.00	0.00
23	0.00	0.00	1.40	2.10	2.80	0.00	0.00	2.10	2.10	4.20	0.00	0.00	2.10	2.10	4.20

SCENARIO

	----------B25 SF----------- MOISTURE RATIO = 0.25					----------B30 SF----------- MOISTURE RATIO = 0.30					----------B45 SF----------- MOISTURE RATIO = 0.45				
	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
YEAR															
1	4.20	2.10	6.30	2.10	2.10	4.20	4.20	4.20	2.10	4.20	4.20	6.30	4.20	2.10	2.10
2	4.20	4.20	2.10	2.10	4.20	4.20	6.30	2.10	2.10	2.10	4.20	6.30	4.20	2.10	2.10
3	0.00	0.00	4.20	2.10	4.20	0.00	0.00	4.20	2.10	4.20	0.00	2.10	4.20	2.10	4.20
4	4.20	4.20	4.20	2.10	4.20	4.20	4.20	4.20	4.20	4.20	4.20	6.30	4.20	4.20	4.20
5	2.10	2.10	0.00	2.10	2.10	2.10	2.10	2.10	0.00	4.20	4.20	2.10	2.10	0.00	4.20
6	2.10	0.00	0.00	2.10	4.20	2.10	0.00	2.10	2.10	2.10	4.20	0.00	0.00	2.10	4.20
7	2.10	2.10	4.20	2.10	4.20	4.20	0.00	4.20	4.20	4.20	4.20	2.10	4.20	4.20	4.20
8	0.00	2.10	4.20	2.10	4.20	0.00	2.10	6.30	0.00	4.20	2.10	2.10	6.30	0.00	4.20
9	2.10	2.10	2.10	0.00	0.00	2.10	2.10	2.10	0.00	0.00	4.20	2.10	2.10	0.00	0.00
10	0.00	0.00	0.00	0.00	2.10	0.00	2.10	0.00	0.00	2.10	2.10	2.10	0.00	2.10	2.10
11	2.10	4.20	2.10	4.20	2.10	4.20	2.10	2.10	4.20	2.10	4.20	4.20	2.10	4.20	2.10
12	2.10	2.10	2.10	0.00	0.00	2.10	2.10	2.10	0.00	0.00	2.10	4.20	2.10	0.00	0.00
13	0.00	0.00	2.10	2.10	2.10	0.00	0.00	2.10	2.10	2.10	0.00	0.00	4.20	2.10	2.10
14	0.00	4.20	2.10	2.10	0.00	0.00	6.30	0.00	2.10	0.00	2.10	6.30	2.10	0.00	0.00
15	4.20	0.00	0.00	0.00	2.10	4.20	0.00	2.10	0.00	0.00	4.20	2.10	0.00	0.00	2.10
16	0.00	0.00	0.00	2.10	2.10	2.10	0.00	0.00	2.10	2.10	2.10	0.00	2.10	2.10	2.10
17	4.20	4.20	2.10	4.20	2.10	4.20	4.20	4.20	2.10	2.10	4.20	6.30	2.10	4.20	2.10
18	4.20	6.30	2.10	4.20	2.10	4.20	6.30	2.10	4.20	4.20	4.20	8.40	2.10	4.20	4.20
19	2.10	4.20	2.10	0.00	4.20	4.20	2.10	2.10	0.00	4.20	4.20	4.20	2.10	0.00	6.30
20	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	4.20	0.00
21	0.00	2.10	0.00	4.20	2.10	0.00	2.10	2.10	2.10	4.20	0.00	4.20	2.10	2.10	4.20
22	0.00	4.20	2.10	2.10	0.00	0.00	4.20	4.20	0.00	0.00	2.10	4.20	4.20	0.00	0.00
23	0.00	0.00	2.10	2.10	4.20	0.00	0.00	2.10	4.20	4.20	2.10	0.00	2.10	4.20	2.10

SCENARIO

	BASE DP			B15 SF MOISTURE RATIO = 0.15			B20 SF MOISTURE RATIO = 0.20			B25 SF MOISTURE RATIO = 0.25		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
YEAR												
1	4	1	1	0	7	0	0	8	0	0	8	0
2	3	2	0	0	7	0	0	7	0	0	8	0
3	2	1	1	0	4	0	0	5	0	0	5	0
4	3	3	1	0	8	0	0	9	0	0	9	0
5	3	1	0	0	4	0	0	4	0	0	4	0
6	2	1	0	0	3	0	0	3	0	0	4	0
7	2	2	1	0	6	0	0	7	0	0	7	0
8	3	1	1	0	5	0	0	6	0	0	6	0
9	3	0	0	0	2	0	0	3	0	0	3	0
10	0	0	0	0	0	0	0	0	0	0	1	0
11	3	1	1	0	6	0	0	6	0	0	7	0
12	2	0	0	0	2	0	0	3	0	0	3	0
13	3	0	0	0	2	0	0	3	0	0	3	0
14	1	0	1	0	3	0	0	4	0	0	4	0
15	2	0	0	0	2	0	0	3	0	0	3	0
16	1	0	0	0	2	0	0	2	0	0	2	0
17	1	1	2	0	7	0	0	7	0	0	8	0
18	5	0	2	0	8	0	0	9	0	0	9	0
19	4	1	0	0	5	0	0	6	0	0	6	0
20	0	0	0	0	0	0	0	1	0	0	1	0
21	3	1	0	0	4	0	0	4	0	0	4	0
22	2	1	0	0	3	0	0	3	0	0	4	0
23	3	1	0	0	4	0	0	4	0	0	4	0

SCENARIO

YEAR	B30 SF MOISTURE RATIO = 0.30 1.4" IRRIG	B30 SF MOISTURE RATIO = 0.30 2.1" IRRIG	B30 SF MOISTURE RATIO = 0.30 2.8" IRRIG	B45 SF MOISTURE RATIO = 0.45 1.4" IRRIG	B45 SF MOISTURE RATIO = 0.45 2.1" IRRIG	B45 SF MOISTURE RATIO = 0.45 2.8" IRRIG
1	0	9	0	0	9	0
2	0	8	0	0	9	0
3	0	5	0	0	6	0
4	0	10	0	0	11	0
5	0	5	0	0	6	0
6	0	4	0	0	5	0
7	0	8	0	0	9	0
8	0	6	0	0	7	0
9	0	3	0	0	4	0
10	0	2	0	0	4	0
11	0	7	0	0	8	0
12	0	3	0	0	4	0
13	0	3	0	0	4	0
14	0	4	0	0	5	0
15	0	3	0	0	4	0
16	0	3	0	0	4	0
17	0	8	0	0	9	0
18	0	10	0	0	11	0
19	0	6	0	0	8	0
20	0	1	0	0	2	0
21	0	5	0	0	6	0
22	0	4	0	0	5	0
23	0	5	0	0	5	0

APPENDIX C

23 YEARS OF SIMULATED GRAIN SORGHUM IRRIGATIONS BY INCHES AND NUMBERS UNDER VARIOUS MARKET PRICES, IRRIGATION VARIABLE COSTS, AND IRRIGATION EFFICIENCIES FOR THE DYNAMIC PROGRAMMING AND SORGF IRRIGATION SCHEDULING MODELS

SCENARIO

	PGS1 DP SORGHUM PRICE = $3.80					PGS1 SF SORGHUM PRICE = $3.80					PGS2 DP SORGHUM PRICE = $5.00					PGS2 SF SORGHUM PRICE = $5.00				
YEAR	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	4.20	3.50	1.40	4.20	2.10	6.30	2.10	2.10	0.00	0.00	6.30	1.40	2.80	4.20	2.10	6.30	2.10	2.10
2	0.00	0.00	3.50	1.40	3.50	4.20	4.20	2.10	2.10	4.20	0.00	0.00	4.20	2.80	2.10	4.20	4.20	2.10	2.10	4.20
3	0.00	0.00	0.00	4.90	2.80	0.00	0.00	4.20	2.10	4.20	0.00	0.00	0.00	4.90	2.80	0.00	0.00	4.20	2.10	4.20
4	1.40	0.00	4.90	3.50	1.40	4.20	4.20	4.20	2.10	4.20	1.40	2.10	4.20	2.80	2.80	4.20	4.20	4.20	2.10	4.20
5	0.00	0.00	0.00	2.80	2.80	2.10	2.10	0.00	2.10	2.10	0.00	0.00	1.40	2.10	2.80	2.10	2.10	0.00	2.10	2.10
6	0.00	0.00	0.00	2.10	2.80	2.10	0.00	0.00	2.10	4.20	0.00	0.00	0.00	2.10	2.80	2.10	0.00	0.00	2.10	4.20
7	0.00	0.00	4.20	2.10	3.50	2.10	2.10	4.20	2.10	4.20	0.00	0.00	4.20	2.10	4.20	2.10	2.10	4.20	2.10	4.20
8	0.00	0.00	4.20	1.40	2.10	0.00	2.10	4.20	2.10	4.20	0.00	0.00	4.20	1.40	3.50	0.00	2.10	4.20	2.10	4.20
9	0.00	0.00	1.40	0.00	1.40	2.10	2.10	2.10	0.00	0.00	0.00	0.00	2.80	0.00	1.40	2.10	2.10	2.10	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10
11	0.00	0.00	4.20	2.10	2.80	2.10	4.20	2.10	4.20	2.10	0.00	0.00	2.80	4.20	1.40	2.10	4.20	2.10	4.20	2.10
12	0.00	0.00	1.40	0.00	0.00	2.10	2.10	2.10	0.00	0.00	0.00	0.00	1.40	1.40	0.00	2.10	2.10	2.10	0.00	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	2.10	2.10	2.10	0.00	0.00	1.40	1.40	1.40	0.00	0.00	2.10	2.10	2.10
14	0.00	0.00	2.80	1.40	0.00	0.00	4.20	2.10	2.10	0.00	0.00	0.00	4.20	1.40	0.00	0.00	4.20	2.10	2.10	0.00
15	1.40	0.00	0.00	0.00	1.40	4.20	0.00	0.00	0.00	2.10	1.40	0.00	0.00	0.00	1.40	4.20	0.00	0.00	0.00	2.10
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	2.10	2.10	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00	2.10	2.10
17	0.00	0.00	3.50	5.60	0.00	4.20	4.20	2.10	4.20	2.10	0.00	0.00	3.50	5.60	0.00	4.20	4.20	2.10	4.20	2.10
18	1.40	0.00	4.20	2.10	2.80	4.20	6.30	2.10	4.20	2.10	1.40	1.40	4.20	2.80	2.80	4.20	6.30	2.10	4.20	2.10
19	0.00	0.00	1.40	3.50	2.80	2.10	4.20	2.10	0.00	4.20	0.00	1.40	0.00	2.80	2.80	2.10	4.20	2.10	0.00	4.20
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00
21	0.00	0.00	1.40	1.40	3.50	0.00	2.10	0.00	4.20	2.10	0.00	0.00	1.40	1.40	3.50	0.00	2.10	0.00	4.20	2.10
22	0.00	0.00	3.50	0.00	0.00	0.00	4.20	2.10	2.10	0.00	0.00	1.40	1.40	2.10	0.00	0.00	4.20	2.10	2.10	0.00
23	0.00	0.00	1.40	2.10	2.80	0.00	0.00	2.10	2.10	4.20	0.00	0.00	1.40	1.40	2.80	0.00	0.00	2.10	2.10	4.20

SCENARIO

YEAR	PGS1 DP SORGHUM PRICE = $3.80			PGS1 SF SORGHUM PRICE = $3.80			PGS2 DP SORGHUM PRICE = $5.00			PGS2 SF SORGHUM PRICE = $5.00		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
1	3	1	1	0	8	0	4	1	1	0	8	0
2	3	2	0	0	8	0	3	1	1	0	8	0
3	2	1	1	0	5	0	2	1	1	0	5	0
4	3	2	1	0	9	0	3	3	1	0	9	0
5	2	0	1	0	4	0	3	1	0	0	4	0
6	2	1	0	0	4	0	2	1	0	0	4	0
7	2	2	1	0	7	0	2	1	2	0	7	0
8	2	1	1	0	6	0	3	1	1	0	6	0
9	2	0	0	0	3	0	3	0	0	0	3	0
10	0	0	0	0	1	0	0	0	0	0	1	0
11	3	1	1	0	7	0	4	0	1	0	7	0
12	1	0	0	0	3	0	2	0	0	0	3	0
13	3	0	0	0	3	0	3	0	0	0	3	0
14	1	0	1	0	4	0	2	0	1	0	4	0
15	2	0	0	0	3	0	2	0	0	0	3	0
16	1	0	0	0	2	0	0	1	0	0	2	0
17	1	1	2	0	8	0	1	1	2	0	8	0
18	4	1	1	0	9	0	5	0	2	0	9	0
19	4	1	0	0	6	0	5	0	0	0	6	0
20	0	0	0	0	1	0	0	0	0	0	1	0
21	3	1	0	0	4	0	3	1	0	0	4	0
22	1	1	0	0	4	0	2	1	0	0	4	0
23	3	1	0	0	4	0	4	0	0	0	4	0

SCENARIO

	IVC1 DP IRRIG VAR COST = $3.40					IVC1 SF IRRIG VAR COST = $3.40					IVC2 DP IRRIG VAR COST = $4.92					IVC2 SF IRRIG VAR COST = $4.92				
YEAR	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	6.30	1.40	2.80	4.20	2 10	6.30	2.10	2.10	0.00	0.00	4.20	3.50	1.40	4 20	2.10	6.30	2.10	2.10
2	0.00	0.00	4.20	3.50	1.40	4.20	4.20	2.10	2.10	4.20	0.00	0.00	2.80	2.80	1.40	4.20	4.20	2.10	2.10	4.20
3	0.00	0.00	0.00	4.90	2.80	0.00	0.00	4.20	2.10	4.20	0.00	0.00	0.00	4.20	2.80	0.00	0 00	4.20	2.10	4.20
4	1 40	2.80	4.20	2.80	2.80	4.20	4.20	4.20	2.10	4.20	1 40	0.00	4.90	3.50	1.40	4.20	4.20	4.20	2.10	4.20
5	0.00	0.00	1.40	2.10	2.80	2.10	2.10	0.00	2.10	2.10	0.00	0.00	0.00	3.50	1.40	2.10	2.10	0.00	2.10	2.10
6	0.00	0.00	0.00	2 10	2.80	2.10	0.00	0.00	2.10	4.20	0 00	0.00	0.00	2.10	2.80	2.10	0.00	0.00	2.10	4.20
7	0.00	0.00	4.20	2.10	4.20	2.10	2.10	4.20	2.10	4.20	0.00	0.00	4.20	2.10	3.50	2.10	2 10	4.20	2.10	4 20
8	0.00	0.00	4.20	1.40	3.50	0.00	2.10	4.20	2.10	4.20	0.00	0.00	4.20	1.40	2.80	0.00	2.10	4.20	2.10	4.20
9	0.00	0.00	2.80	0.00	1.40	2.10	2.10	2.10	0.00	0.00	0.00	0.00	2.10	0.00	0.00	2.10	2.10	2.10	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10
11	0.00	0.00	2.80	2.80	2.80	2.10	4.20	2.10	4.20	2.10	0.00	0.00	4.20	2.10	2.80	2.10	4.20	2.10	4.20	2 10
12	0.00	0.00	1.40	1.40	0.00	2.10	2.10	2.10	0.00	0.00	0.00	0.00	1.40	0.00	0.00	2.10	2.10	2.10	0.00	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	2.10	2.10	2.10	0.00	0.00	1.40	0.00	2.80	0.00	0 00	2.10	2.10	2.10
14	0.00	0.00	4.20	1.40	0.00	0.00	4.20	2.10	2.10	0.00	0.00	0.00	2.80	1.40	0.00	0.00	4.20	2.10	2.10	0 00
15	1.40	0.00	0.00	0.00	2.80	4.20	0.00	0.00	0.00	2.10	1.40	0.00	0.00	0.00	1.40	4.20	0.00	0.00	0.00	2.10
16	0.00	0.00	0.00	0.00	2.80	0.00	0.00	0.00	2.10	2.10	0 00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	2.10	2.10
17	0.00	0.00	4.20	5.60	0.00	4.20	4.20	2.10	4.20	2.10	0.00	0.00	3.50	5.60	0.00	4.20	4.20	2 10	4.20	2.10
18	1.40	2.10	4.20	2.80	2 80	4.20	6.30	2.10	4.20	2.10	1.40	0.00	4.20	2.80	2.80	4.20	6.30	2.10	4.20	2.10
19	0.00	1.40	0.00	2.80	2.80	2.10	4.20	2.10	0.00	4.20	0.00	0.00	1.40	0.00	4.90	2.10	4.20	2.10	0.00	4 20
20	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00
21	0.00	0.00	1.40	1.40	3.50	0.00	2.10	0.00	4.20	2.10	0.00	0 00	1.40	1.40	3.50	0.00	2.10	0.00	4.20	2.10
22	0.00	1.40	1.40	2.10	0.00	0.00	4.20	2.10	2.10	0.00	0 00	0.00	3.50	0.00	0.00	0.00	4.20	2.10	2.10	0 00
23	0.00	0.00	1.40	1.40	3.50	0.00	0.00	2.10	2.10	4.20	0.00	0.00	0.00	1.40	4.20	0.00	0.00	2.10	2.10	4.20

SCENARIO

	IVC1 DP IRRIG VAR COST = $3.40			IVC1 SF IRRIG VAR COST = $3.40			IVC2 DP IRRIG VAR COST = $4.92			IVC2 SF IRRIG VAR COST = $4.92		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
YEAR												
1	4	1	1	0	8	0	3	1	1	0	8	0
2	3	1	1	0	8	0	3	0	1	0	8	0
3	2	1	1	0	5	0	2	2	0	0	5	0
4	3	2	2	0	9	0	3	2	1	0	9	0
5	3	1	0	0	4	0	2	1	0	0	4	0
6	2	1	0	0	4	0	2	1	0	0	4	0
7	2	1	2	0	7	0	2	2	1	0	7	0
8	3	1	1	0	6	0	4	0	1	0	6	0
9	3	0	0	0	3	0	0	1	0	0	3	0
10	0	0	0	0	1	0	0	0	0	0	1	0
11	4	0	1	0	7	0	3	1	1	0	7	0
12	2	0	0	0	3	0	1	0	0	0	3	0
13	3	0	0	0	3	0	3	0	0	0	3	0
14	2	0	1	0	4	0	1	0	1	0	4	0
15	3	0	0	0	3	0	2	0	0	0	3	0
16	0	0	1	0	2	0	1	0	0	0	2	0
17	1	0	3	0	8	0	1	1	2	0	8	0
18	4	1	2	0	9	0	4	0	2	0	9	0
19	5	0	0	0	6	0	3	1	0	0	6	0
20	1	0	0	0	1	0	0	0	0	0	1	0
21	3	1	0	0	4	0	3	1	0	0	4	0
22	2	1	0	0	4	0	1	1	0	0	4	0
23	3	1	0	0	4	0	2	0	1	0	4	0

SCENARIO

	IEF1 DP IRRIG EFFICIENCY = 0.60					IEF1 SF IRRIG EFFICIENCY = 0.60					IEF2 DP IRRIG EFFICIENCY = 0.90					IEF2 SF IRRIG EFFICIENCY = 0.90				
YEAR	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	4.90	4.90	2.10	4.20	6.30	4.20	4.20	2 10	0.00	0.00	4.90	1.40	2.80	2.10	4.20	4.20	0.00	4.20
2	0.00	0.00	3.50	2.80	2.10	4.20	6.30	4.20	2.10	4.20	0 00	0.00	3.50	2.80	1.40	4.20	2.10	2.10	2.10	2.10
3	0.00	0.00	0 00	5.60	3.50	0.00	0.00	4.20	4.20	4.20	0.00	0.00	0.00	4.20	2 80	0.00	0.00	4.20	2.10	2.10
4	2.10	0.00	4.90	4.20	2.10	4 20	6.30	6.30	2.10	6.30	1.40	2.10	3.50	2.10	2.80	4.20	4.20	2.10	2.10	4.20
5	0.00	0.00	0.00	1.40	3.50	2.10	2.10	2.10	0.00	4.20	0.00	0.00	1.40	2.10	1.40	2.10	2.10	0.00	0.00	4.20
6	0.00	0.00	0.00	3.50	2.80	2.10	0.00	2.10	2.10	2.10	0.00	0.00	0.00	2.10	1.40	2.10	0.00	0.00	2.10	2.10
7	0.00	0.00	4.20	2.80	4.90	2 10	2.10	4.20	4.20	6.30	0.00	0.00	4.20	1.40	3.50	2 10	2.10	2.10	2.10	4.20
8	0.00	0 00	4.20	1.40	4.20	0.00	2.10	6 30	2.10	4 20	0.00	0.00	4.20	0.00	3 50	0.00	2.10	4.20	0.00	4.20
9	0.00	0.00	1.40	0.00	2.80	2.10	2.10	2.10	0 00	2.10	0.00	0.00	2.80	0.00	0.00	2.10	0.00	2.10	0 00	2.10
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10
11	0.00	0.00	4.20	4.20	1.40	2.10	6.30	2.10	4.20	4.20	0 00	0.00	2.80	2.10	2.80	2.10	2.10	4.20	2.10	2 10
12	0.00	0.00	2.10	0.00	0.00	2.10	2.10	2.10	0.00	0.00	0.00	0.00	1.40	1.40	0.00	2.10	0.00	2.10	0.00	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	2.10	2.10	4.20	0.00	0.00	1.40	0.00	2.80	0 00	0 00	2.10	2.10	2.10
14	0.00	0.00	2.80	2.10	0.00	0.00	4.20	4.20	2.10	0.00	0.00	0.00	3.50	1.40	0 00	0 00	4.20	2.10	0.00	0 00
15	1.40	0.00	0.00	0.00	1.40	4.20	0.00	2.10	0.00	0.00	1.40	0.00	0.00	0.00	1.40	4.20	0 00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	2.10	4.20	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00	2 10	2.10
17	0.00	0.00	4.90	2.80	2.10	4.20	6.30	4.20	4.20	0.00	0.00	0 00	3.50	4.90	0.00	4.20	2.10	4.20	2.10	0 00
18	1.40	0.00	4.20	2.80	3.50	4.20	8.40	4.20	4.20	4.20	1.40	1.40	3.50	2.10	2.80	4.20	4.20	2.10	2.10	4.20
19	0.00	0.00	1.40	1.40	5.60	4.20	2.10	2.10	0.00	8.40	0.00	1.40	0.00	2 80	2.80	2 10	2.10	2.10	0.00	4.20
20	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	2 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00
21	0.00	0.00	1.40	1.40	4.20	0.00	2.10	0.00	4.20	4.20	0.00	0.00	1.40	2.80	1.40	0 00	2.10	0.00	2.10	4.20
22	0.00	0.00	4.20	0.00	0.00	0.00	4.20	4.20	2.10	0.00	0 00	1.40	1.40	1.40	0.00	0.00	4.20	2.10	0.00	0 00
23	0.00	0.00	1.40	2.80	2.80	0.00	0.00	2.10	4.20	4.20	0.00	0.00	1.40	2.10	1.40	0.00	0.00	2.10	2 10	4.20

SCENARIO

	IEF1 DP IRRIG EFFICIENCY = 0.60			IEF1 SF IRRIG EFFICIENCY = 0.60			IEF2 DP IRRIG EFFICIENCY = 0.90			IEF2 SF IRRIG EFFICIENCY = 0.90		
YEAR	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
1	0	3	2	0	10	0	5	1	0	0	7	0
2	1	2	1	0	10	0	4	1	0	0	6	0
3	1	1	2	0	6	0	2	2	0	0	4	0
4	0	5	1	0	12	0	4	3	0	0	8	0
5	2	1	0	0	5	0	2	1	0	0	4	0
6	3	1	0	0	4	0	1	1	0	0	3	0
7	1	1	3	0	9	0	3	1	1	0	6	0
8	2	2	1	0	7	0	2	1	1	0	5	0
9	3	0	0	0	4	0	2	0	0	0	3	0
10	0	0	0	0	1	0	0	0	0	0	1	0
11	3	0	2	0	9	0	4	1	0	0	6	0
12	0	1	0	0	3	0	2	0	0	0	2	0
13	3	0	0	0	4	0	3	0	0	0	3	0
14	0	1	1	0	5	0	2	1	0	0	3	0
15	2	0	0	0	3	0	2	0	0	0	2	0
16	1	0	0	0	3	0	0	1	0	0	2	0
17	0	2	2	0	9	0	1	2	1	0	6	0
18	3	1	2	0	12	0	5	2	0	0	8	0
19	4	0	1	0	8	0	5	0	0	0	5	0
20	0	0	0	0	1	0	0	0	0	0	1	0
21	3	0	1	0	5	0	4	0	0	0	4	0
22	1	0	1	0	5	0	3	0	0	0	3	0
23	3	0	1	0	5	0	2	1	0	0	4	0

APPENDIX D

23 YEARS OF SIMULATED GRAIN SORGHUM IRRIGATIONS BY INCHES AND NUMBERS UNDER VARIOUS MARKET PRICES, IRRIGATION VARIABLE COSTS, AND IRRIGATION EFFICIENCIES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL

SCENARIO

YEAR	BASE DP SORGHUM PRICE = $4.40 PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PGS1 DP SORGHUM PRICE = $3.80 PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PGS2 DP SORGHUM PRICE = $5.00 PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	6.30	1.40	2.80	0.00	0.00	4.20	3.50	1.40	0.00	0.00	6.30	1.40	2.80
2	0.00	0.00	4.20	2.80	1.40	0.00	0.00	3.50	1.40	3.50	0.00	0.00	4.20	2.80	2.10
3	0.00	0.00	0.00	4.90	2.80	0.00	0.00	0.00	4.90	2.80	0.00	0.00	0.00	4.90	2.80
4	1.40	2.10	4.20	2.80	2.80	1.40	0.00	4.90	3.50	1.40	1.40	2.10	4.20	2.80	2.80
5	0.00	0.00	1.40	2.10	2.80	0.00	0.00	0.00	2.80	2.80	0.00	0.00	1.40	2.10	2.80
6	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	2.80
7	0.00	0.00	4.20	2.10	3.50	0.00	0.00	4.20	2.10	3.50	0.00	0.00	4.20	2.10	4.20
8	0.00	0.00	4.20	1.40	3.50	0.00	0.00	4.20	1.40	2.10	0.00	0.00	4.20	1.40	3.50
9	0.00	0.00	2.80	0.00	1.40	0.00	0.00	1.40	0.00	1.40	0.00	0.00	2.80	0.00	1.40
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	4.20	2.10	2.80	0.00	0.00	4.20	2.10	2.80	0.00	0.00	2.80	4.20	1.40
12	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40	1.40	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40
14	0.00	0.00	2.80	1.40	0.00	0.00	0.00	2.80	1.40	0.00	0.00	0.00	4.20	1.40	0.00
15	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	2.10
17	0.00	0.00	3.50	5.60	0.00	0.00	0.00	3.50	5.60	0.00	0.00	0.00	3.50	5.60	0.00
18	1.40	0.00	2.80	5.60	2.80	1.40	0.00	4.20	2.10	2.80	1.40	1.40	4.20	2.80	2.80
19	0.00	1.40	0.00	3.50	2.80	0.00	0.00	1.40	3.50	2.80	0.00	1.40	0.00	2.80	2.80
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	1.40	3.50
22	0.00	0.00	3.50	1.40	0.00	0.00	0.00	3.50	0.00	0.00	0.00	1.40	1.40	2.10	0.00
23	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	1.40	2.80

SCENARIO

	BASE DP SORGHUM PRICE = $4.40			PGS1 DP SORGHUM PRICE = $3.80			PGS2 DP SORGHUM PRICE = $5.00		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
YEAR									
1	4	1	1	3	1	1	4	1	1
2	3	2	0	3	2	0	3	1	1
3	2	1	1	2	1	1	2	1	1
4	3	3	1	3	2	1	3	3	1
5	3	1	0	2	0	1	3	1	0
6	2	1	0	2	1	0	2	1	0
7	2	2	1	2	2	1	2	1	2
8	3	1	1	2	1	1	3	1	1
9	3	0	0	2	0	0	3	0	0
10	0	0	0	0	0	0	0	0	0
11	3	1	1	3	1	1	4	0	1
12	2	0	0	1	0	0	2	0	0
13	3	0	0	3	0	0	3	0	0
14	1	0	1	1	0	1	2	0	1
15	2	0	0	2	0	0	2	0	0
16	1	0	0	1	0	0	0	1	0
17	1	1	2	1	1	2	1	1	2
18	5	0	2	4	1	1	5	0	2
19	4	1	0	4	1	0	5	0	0
20	0	0	0	0	0	0	0	0	0
21	3	1	0	3	1	0	3	1	0
22	2	1	0	1	1	0	2	1	0
23	3	1	0	3	1	0	4	0	0

	SCENARIO														
	BASE DP IRRIG COST = $4.16				VAR	IVC1 DP IRRIG COST = $3.40				VAR	IVC2 DP IRRIG COST = $4.92				VAR
	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
YEAR															
1	0.00	0.00	6.30	1.40	2.80	0.00	0.00	6.30	1.40	2.80	0.00	0.00	4.20	3.50	1.40
2	0.00	0.00	4.20	2.80	1.40	0.00	0.00	4.20	3.50	1.40	0.00	0.00	2.80	2.80	1.40
3	0.00	0.00	0.00	4.90	2.80	0.00	0.00	0.00	4.90	2.80	0.00	0.00	0.00	4.20	2.80
4	1.40	2.10	4.20	2.80	2.80	1.40	2.80	4.20	2.80	2.80	1.40	0.00	4.90	3.50	1.40
5	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	2.10	2.80	0.00	0.00	0.00	3.50	1.40
6	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	2.80
7	0.00	0.00	4.20	2.10	3.50	0.00	0.00	4.20	2.10	4.20	0.00	0.00	4.20	2.10	3.50
8	0.00	0.00	4.20	1.40	3.50	0.00	0.00	4.20	1.40	3.50	0.00	0.00	4.20	1.40	2.80
9	0.00	0.00	2.80	0.00	1.40	0.00	0.00	2.80	0.00	1.40	0.00	0.00	2.10	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	4.20	2.10	2.80	0.00	0.00	2.80	2.80	2.80	0.00	0.00	4.20	2.10	2.80
12	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	0.00	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	0.00	2.80
14	0.00	0.00	2.80	1.40	0.00	0.00	0.00	4.20	1.40	0.00	0.00	0.00	2.80	1.40	0.00
15	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	2.80	1.40	0.00	0.00	0.00	1.40
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	2.80	0.00	0.00	0.00	0.00	1.40
17	0.00	0.00	3.50	5.60	0.00	0.00	0.00	4.20	5.60	0.00	0.00	0.00	3.50	5.60	0.00
18	1.40	0.00	2.80	5.60	2.80	1.40	2.10	4.20	2.80	2.80	1.40	0.00	4.20	2.80	2.80
19	0.00	1.40	0.00	3.50	2.80	0.00	1.40	0.00	2.80	2.80	0.00	0.00	1.40	0.00	4.90
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	1.40	3.50
22	0.00	0.00	3.50	1.40	0.00	0.00	1.40	1.40	2.10	0.00	0.00	0.00	3.50	0.00	0.00
23	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	1.40	3.50	0.00	0.00	0.00	1.40	4.20

SCENARIO

	BASE DP VAR IRRIG COST = $4.16			IVC1 DP VAR IRRIG COST = $3.40			IVC2 DP VAR IRRIG COST = $4.92		
YEAR	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
1	4	1	1	4	1	1	3	1	1
2	3	2	0	3	1	1	3	0	1
3	2	1	1	2	1	1	2	2	0
4	3	3	1	3	2	2	3	2	1
5	3	1	0	3	1	0	2	1	0
6	2	1	0	2	1	0	2	1	0
7	2	2	1	2	1	2	2	2	1
8	3	1	1	3	1	1	4	0	1
9	3	0	0	3	0	0	0	1	0
10	0	0	0	0	0	0	0	0	0
11	3	1	1	4	0	1	3	1	1
12	2	0	0	2	0	0	1	0	0
13	3	0	0	3	0	0	3	0	0
14	1	0	1	2	0	1	1	0	1
15	2	0	0	3	0	0	2	0	0
16	1	0	0	0	0	1	1	0	0
17	1	1	2	1	0	3	1	1	2
18	5	0	2	4	1	2	4	0	2
19	4	1	0	5	0	0	3	1	0
20	0	0	0	1	0	0	0	0	0
21	3	1	0	3	1	0	3	1	0
22	2	1	0	2	1	0	1	1	0
23	3	1	0	3	1	0	2	0	1

SCENARIO

	----------BASE DP---------- IRRIG EFFICIENCY = 0.75					----------IEF1 DP---------- IRRIG EFFICIENCY = 0.60					----------IEF2 DP---------- IRRIG EFFICIENCY = 0.90				
YEAR	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	6.30	1.40	2.80	0.00	0.00	4.90	4.90	2.10	0.00	0.00	4.90	1.40	2.80
2	0.00	0.00	4.20	2.80	1.40	0.00	0.00	3.50	2.80	2.10	0.00	0.00	3.50	2.80	1.40
3	0.00	0.00	0.00	4.90	2.80	0.00	0.00	0.00	5.60	3.50	0.00	0.00	0.00	4.20	2.80
4	1.40	2.10	4.20	2.80	2.80	2.10	0.00	4.90	4.20	2.10	1.40	2.10	3.50	2.10	2.80
5	0.00	0.00	1.40	2.10	2.80	0.00	0.00	0.00	1.40	3.50	0.00	0.00	1.40	2.10	1.40
6	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	3.50	2.80	0.00	0.00	0.00	2.10	1.40
7	0.00	0.00	4.20	2.10	3.50	0.00	0.00	4.20	2.80	4.90	0.00	0.00	4.20	1.40	3.50
8	0.00	0.00	4.20	1.40	3.50	0.00	0.00	4.20	1.40	4.20	0.00	0.00	4.20	0.00	3.50
9	0.00	0.00	2.80	0.00	1.40	0.00	0.00	1.40	0.00	2.80	0.00	0.00	2.80	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	4.20	2.10	2.80	0.00	0.00	4.20	4.20	1.40	0.00	0.00	2.80	2.10	2.80
12	0.00	0.00	1.40	1.40	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	1.40	1.40	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	0.00	2.80
14	0.00	0.00	2.80	1.40	0.00	0.00	0.00	2.80	2.10	0.00	0.00	0.00	3.50	1.40	0.00
15	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	2.10
17	0.00	0.00	3.50	5.60	0.00	0.00	0.00	4.90	2.80	2.10	0.00	0.00	3.50	4.90	0.00
18	1.40	0.00	2.80	5.60	2.80	1.40	0.00	4.20	2.80	3.50	1.40	1.40	3.50	2.10	2.80
19	0.00	1.40	0.00	3.50	2.80	0.00	0.00	1.40	1.40	5.60	0.00	1.40	0.00	2.80	2.80
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	1.40	4.20	0.00	0.00	1.40	2.80	1.40
22	0.00	0.00	3.50	1.40	0.00	0.00	0.00	4.20	0.00	0.00	0.00	1.40	1.40	1.40	0.00
23	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	2.80	2.80	0.00	0.00	1.40	2.10	1.40

SCENARIO

	----------BASE DP-------- IRRIG EFFICIENCY = 0.75			----------IEF1 DP-------- IRRIG EFFICIENCY = 0.60			----------IEF2 DP-------- IRRIG EFFICIENCY = 0.90		
YEAR	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
1	4	1	1	0	3	2	5	1	0
2	3	2	0	1	2	1	4	1	0
3	2	1	1	1	1	2	2	2	0
4	3	3	1	0	5	1	4	3	0
5	3	1	0	2	1	0	2	1	0
6	2	1	0	3	1	0	1	1	0
7	2	2	1	1	1	3	3	1	1
8	3	1	1	2	2	1	2	1	1
9	3	0	0	3	0	0	2	0	0
10	0	0	0	0	0	0	0	0	0
11	3	1	1	3	0	2	4	1	0
12	2	0	0	0	1	0	2	0	0
13	3	0	0	3	0	0	3	0	0
14	1	0	1	0	1	1	2	1	0
15	2	0	0	2	0	0	2	0	0
16	1	0	0	1	0	0	0	1	0
17	1	1	2	0	2	2	1	2	1
18	5	0	2	3	1	2	5	2	0
19	4	1	0	4	0	1	5	0	0
20	0	0	0	0	0	0	0	0	0
21	3	1	0	3	0	1	4	0	0
22	2	1	0	1	0	1	3	0	0
23	3	1	0	3	0	1	2	1	0

APPENDIX E

23 YEARS OF SIMULATED GRAIN SORGHUM IRRIGATIONS BY INCHES AND NUMBERS UNDER VARIOUS MARKET PRICES, IRRIGATION VARIABLE COSTS, AND IRRIGATION EFFICIENCIES FOR THE DYNAMIC PROGRAMMING IRRIGATION SCHEDULING MODEL WITH LOW PRESSURE, HIGH PRESSURE AND LEPA IRRIGATION SYSTEMS

SCENARIO

	--------1 HPRS DP---------- PSI = 60 EFF = .60					--------2 LPRS DP---------- PSI = 30 EFF = .75					--------3 LEPA DP---------- PSI = 10 EFF = .95				
YEAR	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	4.90	2.10	2.80	0.00	0.00	6.30	1.40	2.80	0.00	0.00	4.90	1.40	2.80
2	0.00	0.00	3.50	2.80	2.10	0.00	0.00	4.20	2.80	1.40	0.00	0.00	3.50	2.80	1.40
3	0.00	0.00	0.00	5.60	3.50	0.00	0.00	0.00	4.90	2.80	0.00	0.00	0.00	4.20	2.80
4	2.10	0.00	2.80	5.60	3.50	1.40	2.10	4.20	2.80	2.80	1.40	2.10	3.50	2.10	2.80
5	0.00	0.00	0.00	1.40	4.20	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	1.40	1.40
6	0.00	0.00	0.00	2.10	3.50	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	1.40
7	0.00	0.00	4.20	2.10	3.50	0.00	0.00	4.20	2.10	3.50	0.00	0.00	4.20	1.40	3.50
8	0.00	0.00	4.20	1.40	3.50	0.00	0.00	4.20	1.40	3.50	0.00	0.00	3.50	1.40	2.80
9	0.00	0.00	0.00	1.40	1.40	0.00	0.00	2.80	0.00	1.40	0.00	0.00	2.80	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	4.20	2.80	2.80	0.00	0.00	4.20	2.10	2.80	0.00	0.00	2.80	2.10	2.80
12	0.00	0.00	0.00	1.40	1.40	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00
13	0.00	0.00	1.40	2.10	1.40	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40
14	0.00	0.00	2.80	2.10	0.00	0.00	0.00	2.80	1.40	0.00	0.00	0.00	3.50	1.40	0.00
15	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	2.10
17	0.00	0.00	4.90	2.80	1.40	0.00	0.00	3.50	5.60	0.00	0.00	0.00	3.50	4.20	0.00
18	1.40	0.00	4.20	2.80	3.50	1.40	0.00	2.80	5.60	2.80	1.40	1.40	3.50	2.10	2.80
19	0.00	0.00	1.40	2.80	3.50	0.00	1.40	0.00	3.50	2.80	0.00	1.40	0.00	2.80	2.80
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	1.40	1.40	4.20	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	2.80	1.40
22	0.00	0.00	1.40	2.10	0.00	0.00	0.00	3.50	1.40	0.00	0.00	1.40	1.40	1.40	0.00
23	0.00	0.00	0.00	2.10	4.90	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	1.40	2.10

	SCENARIO								
	--------1 HPRS DP------- PSI = 60 EFF = .60			--------2 LPRS DP------- PSI = 30 EFF = .75			--------3 LEPA DP------- PSI = 10 EFF = .95		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
YEAR									
1	2	2	1	4	1	1	5	1	0
2	1	2	1	3	2	0	4	1	0
3	1	1	2	2	1	1	2	2	0
4	1	2	3	3	3	1	4	3	0
5	2	0	1	3	1	0	3	0	0
6	1	2	0	2	1	0	1	1	0
7	2	2	1	2	2	1	3	1	1
8	3	1	1	3	1	1	4	1	0
9	2	0	0	3	0	0	2	0	0
10	0	0	0	0	0	0	0	0	0
11	3	0	2	3	1	1	4	1	0
12	2	0	0	2	0	0	2	0	0
13	2	1	0	3	0	0	3	0	0
14	0	1	1	1	0	1	2	1	0
15	2	0	0	2	0	0	2	0	0
16	1	0	0	1	0	0	0	1	0
17	1	1	2	1	1	2	1	3	0
18	3	1	2	5	0	2	5	2	0
19	2	1	1	4	1	0	5	0	0
20	0	0	0	0	0	0	0	0	0
21	3	0	1	3	1	0	4	0	0
22	1	1	0	2	1	0	3	0	0
23	0	2	1	3	1	0	2	1	0

SCENARIO

	--------1 HPR3 DP---------- SORGHUM PRICE = $3.80					--------2 LPR3 DP---------- SORGHUM PRICE = $3.80					--------3 LEP3 DP---------- SORGHUM PRICE = $3.80				
YEAR	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	4.90	2.10	2.80	0.00	0.00	4.20	3.50	1.40	0.00	0.00	4.90	1.40	1.40
2	0.00	0.00	2.80	3.50	2.10	0.00	0.00	3.50	1.40	3.50	0.00	0.00	3.50	2.80	1.40
3	0.00	0.00	0.00	4.90	3.50	0.00	0.00	0.00	4.90	2.80	0.00	0.00	0.00	4.20	2.80
4	2.10	0.00	2.80	4.90	1.40	1.40	0.00	4.90	3.50	1.40	1.40	2.10	3.50	2.10	1.40
5	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.80	2.80	0.00	0.00	1.40	1.40	1.40
6	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.80	1.40
7	0.00	0.00	1.40	4.90	3.50	0.00	0.00	4.20	2.10	3.50	0.00	0.00	3.50	1.40	3.50
8	0.00	0.00	2.80	1.40	4.90	0.00	0.00	4.20	1.40	2.10	0.00	0.00	3.50	1.40	2.80
9	0.00	0.00	0.00	1.40	1.40	0.00	0.00	1.40	0.00	1.40	0.00	0.00	2.80	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	1.40	2.80	2.80	0.00	0.00	4.20	2.10	2.80	0.00	0.00	2.80	2.10	1.40
12	0.00	0.00	0.00	2.10	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40	1.40	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	0.00	2.80
14	0.00	0.00	2.80	2.10	0.00	0.00	0.00	2.80	1.40	0.00	0.00	0.00	3.50	1.40	0.00
15	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	2.10
17	0.00	0.00	2.80	2.80	0.00	0.00	0.00	3.50	5.60	0.00	0.00	0.00	3.50	4.20	0.00
18	1.40	0.00	4.20	2.80	3.50	1.40	0.00	4.20	2.10	2.80	1.40	1.40	3.50	2.10	2.80
19	0.00	0.00	0.00	3.50	3.50	0.00	0.00	1.40	3.50	2.80	0.00	1.40	0.00	2.80	2.80
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	2.80	4.20	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	1.40	2.80
22	0.00	0.00	2.80	0.00	0.00	0.00	0.00	3.50	0.00	0.00	0.00	1.40	2.10	0.00	0.00
23	0.00	0.00	0.00	2.10	4.20	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	1.40	2.80

SCENARIO

	--------1 HPR3 DP------- SORGHUM PRICE = $3.80			--------2 LPR3 DP------- SORGHUM PRICE = $3.80			--------3 LEP3 DP------- SORGHUM PRICE = $3.80		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
YEAR									
1	2	2	1	3	1	1	4	1	0
2	1	2	1	3	2	0	4	1	0
3	1	2	1	2	1	1	2	2	0
4	1	2	2	3	2	1	3	3	0
5	2	1	0	2	0	1	3	0	0
6	2	1	0	2	1	0	3	0	0
7	2	2	1	2	2	1	3	2	0
8	1	1	2	2	1	1	4	1	0
9	2	0	0	2	0	0	2	0	0
10	0	0	0	0	0	0	0	0	0
11	1	0	2	3	1	1	3	1	0
12	0	1	0	1	0	0	2	0	0
13	3	0	0	3	0	0	3	0	0
14	0	1	1	1	0	1	2	1	0
15	2	0	0	2	0	0	2	0	0
16	1	0	0	1	0	0	0	1	0
17	0	0	2	1	1	2	1	3	0
18	3	1	2	4	1	1	5	2	0
19	2	2	0	4	1	0	5	0	0
20	0	0	0	0	0	0	0	0	0
21	2	2	0	3	1	0	4	0	0
22	0	0	1	1	1	0	1	1	0
23	1	1	1	3	1	0	4	0	0

SCENARIO

YEAR	--------1 HPR4 DP---------- SORGHUM PRICE = $5.00					--------2 LPR4 DP---------- SORGHUM PRICE = $5.00					--------3 LEP4 DP---------- SORGHUM PRICE = $5.00				
	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	0.00	0.00	4.90	4.90	2.10	0.00	0.00	6.30	1.40	2.80	0.00	0.00	5.60	1.40	1.40
2	0.00	0.00	3.50	2.80	2.10	0.00	0.00	4.20	2.80	2.10	0.00	0.00	3.50	2.80	1.40
3	0.00	0.00	0.00	5.60	3.50	0.00	0.00	0.00	4.90	2.80	0.00	0.00	0.00	4.20	2.80
4	2.10	0.00	4.90	4.20	2.10	1.40	2.10	4.20	2.80	2.80	1.40	2.10	3.50	2.10	2.80
5	0.00	0.00	0.00	2.80	3.50	0.00	0.00	1.40	2.10	2.80	0.00	0.00	1.40	2.10	1.40
6	0.00	0.00	0.00	3.50	1.40	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	1.40
7	0.00	0.00	4.20	2.80	4.90	0.00	0.00	4.20	2.10	4.20	0.00	0.00	4.20	1.40	3.50
8	0.00	0.00	4.20	1.40	2.80	0.00	0.00	4.20	1.40	3.50	0.00	0.00	4.20	0.00	3.50
9	0.00	0.00	2.10	0.00	1.40	0.00	0.00	2.80	0.00	1.40	0.00	0.00	2.80	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	4.20	2.80	2.80	0.00	0.00	2.80	4.20	1.40	0.00	0.00	2.80	3.50	1.40
12	0.00	0.00	2.10	0.00	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40
14	0.00	0.00	2.80	2.10	0.00	0.00	0.00	4.20	1.40	0.00	0.00	0.00	3.50	1.40	0.00
15	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00	1.40
17	0.00	0.00	4.90	2.80	2.10	0.00	0.00	3.50	5.60	0.00	0.00	0.00	3.50	4.20	0.00
18	1.40	0.00	4.90	2.80	3.50	1.40	1.40	4.20	2.80	2.80	1.40	1.40	3.50	2.10	2.80
19	0.00	0.00	1.40	2.10	3.50	0.00	1.40	0.00	2.80	2.80	0.00	1.40	0.00	2.80	2.80
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	1.40	1.40	4.20	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	2.80	1.40
22	0.00	0.00	4.20	0.00	0.00	0.00	1.40	1.40	2.10	0.00	0.00	1.40	1.40	1.40	0.00
23	0.00	0.00	0.00	2.10	4.90	0.00	0.00	1.40	1.40	2.80	0.00	0.00	1.40	1.40	2.80

SCENARIO

	--------1 HPR4 DP------- SORGHUM PRICE = $5.00			--------2 LPR4 DP------- SORGHUM PRICE = $5.00			--------3 LEP4 DP------- SORGHUM PRICE = $5.00		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
YEAR									
1	0	3	2	4	1	1	3	2	0
2	1	2	1	3	1	1	4	1	0
3	1	1	2	2	1	1	2	2	0
4	0	5	1	3	3	1	4	3	0
5	1	1	1	3	1	0	2	1	0
6	2	1	0	2	1	0	1	1	0
7	1	1	3	2	1	2	3	1	1
8	2	0	2	3	1	1	2	1	1
9	1	1	0	3	0	0	2	0	0
10	0	0	0	0	0	0	0	0	0
11	3	0	2	4	0	1	4	1	0
12	0	1	0	2	0	0	2	0	0
13	3	0	0	3	0	0	3	0	0
14	0	1	1	2	0	1	2	1	0
15	2	0	0	2	0	0	2	0	0
16	1	0	0	0	1	0	1	0	0
17	0	2	2	1	1	2	1	3	0
18	2	2	2	5	0	2	5	2	0
19	2	2	0	5	0	0	5	0	0
20	0	0	0	0	0	0	0	0	0
21	3	0	1	3	1	0	4	0	0
22	1	0	1	2	1	0	3	0	0
23	0	2	1	4	0	0	4	0	0

SCENARIO

	--------1 HPR1 DP---------- IRRIG VAR COST = 3.86					--------2 LPR1 DP---------- IRRIG VAR COST = 3.40					--------3 LEP1 DP---------- IRRIG VAR COST = 3.28				
	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
YEAR															
1	0.00	0.00	4.90	4.90	1.40	0.00	0.00	6.30	1.40	2.80	0.00	0.00	5.60	1.40	2.80
2	0.00	0.00	4.20	2.10	3.50	0.00	0.00	4.20	3.50	1.40	0.00	2.80	2.80	1.40	1.40
3	0.00	0.00	0.00	5.60	3.50	0.00	0.00	0.00	4.90	2.80	0.00	0.00	2.10	2.80	1.40
4	2.10	0.00	4.90	2.10	3.50	1.40	2.80	4.20	2.80	2.80	1.40	2.10	3.50	2.10	2.80
5	0.00	0.00	0.00	4.20	2.80	0.00	0.00	1.40	2.10	2.80	0.00	1.40	0.00	1.40	2.80
6	0.00	0.00	0.00	3.50	2.80	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	2.80
7	0.00	0.00	4.20	2.80	4.90	0.00	0.00	4.20	2.10	4.20	0.00	0.00	2.80	3.50	2.80
8	0.00	0.00	4.20	1.40	4.90	0.00	0.00	4.20	1.40	3.50	0.00	0.00	4.20	1.40	1.40
9	0.00	0.00	2.80	0.00	1.40	0.00	0.00	2.80	0.00	1.40	0.00	0.00	2.80	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	4.20	2.80	2.80	0.00	0.00	2.80	2.80	2.80	0.00	0.00	2.80	3.50	1.40
12	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	1.40	1.40
14	0.00	0.00	2.80	2.80	0.00	0.00	0.00	4.20	1.40	0.00	0.00	0.00	3.50	1.40	0.00
15	1.40	0.00	0.00	0.00	2.80	1.40	0.00	0.00	0.00	2.80	1.40	0.00	0.00	0.00	1.40
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	2.80	0.00	0.00	0.00	1.40	1.40
17	0.00	0.00	4.20	5.60	0.00	0.00	0.00	4.20	5.60	0.00	0.00	2.10	3.50	2.10	1.40
18	1.40	0.00	4.20	2.80	3.50	1.40	2.10	4.20	2.80	2.80	1.40	1.40	3.50	2.10	2.80
19	0.00	0.00	1.40	3.50	3.50	0.00	1.40	0.00	2.80	2.80	0.00	1.40	0.00	2.80	2.80
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	1.40	1.40	4.20	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	2.80	1.40
22	0.00	0.00	4.20	0.00	0.00	0.00	1.40	1.40	2.10	0.00	0.00	1.40	1.40	1.40	0.00
23	0.00	0.00	1.40	2.80	2.80	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	1.40	2.80

SCENARIO

	--------1 HPR1 DP-------			--------2 LPR1 DP-------			--------3 LEP1 DP-------		
	IRRIG VAR COST = 3.86			IRRIG VAR COST = 3.40			IRRIG VAR COST = 3.28		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
YEAR									
1	1	2	2	4	1	1	4	2	0
2	1	4	0	3	1	1	4	0	1
3	1	1	2	2	1	1	3	1	0
4	1	4	1	3	2	2	4	3	0
5	3	0	1	3	1	0	4	0	0
6	3	1	0	2	1	0	2	1	0
7	1	1	3	2	1	2	5	1	0
8	2	1	2	3	1	1	3	0	1
9	3	0	0	3	0	0	2	0	0
10	0	0	0	0	0	0	0	0	0
11	3	0	2	4	0	1	4	1	0
12	2	0	0	2	0	0	2	0	0
13	3	0	0	3	0	0	3	0	0
14	0	0	2	2	0	1	2	1	0
15	3	0	0	3	0	0	2	0	0
16	1	0	0	0	0	1	2	0	0
17	0	2	2	1	0	3	2	3	0
18	3	1	2	4	1	2	5	2	0
19	3	2	0	5	0	0	5	0	0
20	0	0	0	1	0	0	0	0	0
21	3	0	1	3	1	0	4	0	0
22	1	0	1	2	1	0	3	0	0
23	3	0	1	3	1	0	4	0	0

	SCENARIO														
	--------1 HPR2 DP---------- IRRIG VAR COST = 5.71					--------2 LPR2 DP---------- IRRIG VAR COST = 4.92					--------3 LEP2 DP---------- IRRIG VAR COST = 4.58				
	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PRE-EMERGE	STAGE 1	STAGE 2	STAGE 3	STAGE 4
YEAR															
1	0.00	0.00	4.20	2.10	2.80	0.00	0.00	4.20	3.50	1.40	0.00	0.00	4.90	1.40	1.40
2	0.00	0.00	2.80	3.50	1.40	0.00	0.00	2.80	2.80	1.40	0.00	0.00	3.50	2.80	1.40
3	0.00	0.00	0.00	4.90	3.50	0.00	0.00	0.00	4.20	2.80	0.00	0.00	0.00	4.20	2.80
4	2.10	0.00	2.80	2.80	3.50	1.40	0.00	4.90	3.50	1.40	1.40	2.10	3.50	2.10	1.40
5	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	3.50	1.40	0.00	0.00	1.40	1.40	1.40
6	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.10	2.80	0.00	0.00	0.00	2.80	1.40
7	0.00	0.00	1.40	4.90	3.50	0.00	0.00	4.20	2.10	3.50	0.00	0.00	3.50	1.40	3.50
8	0.00	0.00	2.80	1.40	4.20	0.00	0.00	4.20	1.40	2.80	0.00	0.00	3.50	1.40	2.80
9	0.00	0.00	1.40	0.00	1.40	0.00	0.00	2.10	0.00	0.00	0.00	0.00	2.80	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	1.40	2.80	2.80	0.00	0.00	4.20	2.10	2.80	0.00	0.00	2.80	2.10	1.40
12	0.00	0.00	0.00	2.10	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40	1.40	0.00
13	0.00	0.00	1.40	1.40	1.40	0.00	0.00	1.40	0.00	2.80	0.00	0.00	1.40	0.00	2.80
14	0.00	0.00	2.80	2.10	0.00	0.00	0.00	2.80	1.40	0.00	0.00	0.00	2.80	1.40	0.00
15	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40	1.40	0.00	0.00	0.00	1.40
16	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.40
17	0.00	0.00	2.80	2.80	1.40	0.00	0.00	3.50	5.60	0.00	0.00	0.00	3.50	4.20	0.00
18	1.40	0.00	1.40	5.60	3.50	1.40	0.00	4.20	2.80	2.80	1.40	1.40	3.50	2.10	2.80
19	0.00	0.00	0.00	3.50	3.50	0.00	0.00	1.40	0.00	4.90	0.00	1.40	0.00	2.80	2.80
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	4.20	2.10	0.00	0.00	1.40	1.40	3.50	0.00	0.00	1.40	1.40	2.80
22	0.00	0.00	2.80	0.00	0.00	0.00	0.00	3.50	0.00	0.00	0.00	1.40	2.10	0.00	0.00
23	0.00	0.00	0.00	2.10	4.20	0.00	0.00	0.00	1.40	4.20	0.00	0.00	1.40	1.40	2.80

SCENARIO

	--------1 HPR2 DP------- IRRIG VAR COST = 5.71			--------2 LPR2 DP------- IRRIG VAR COST = 4.92			--------3 LEP2 DP------- IRRIG VAR COST = 4.58		
	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG	1.4" IRRIG	2.1" IRRIG	2.8" IRRIG
YEAR									
1	3	1	1	3	1	1	4	1	0
2	2	1	1	3	0	1	4	1	0
3	1	2	1	2	2	0	2	2	0
4	1	2	2	3	2	1	3	3	0
5	2	1	0	2	1	0	3	0	0
6	2	1	0	2	1	0	3	0	0
7	2	2	1	2	2	1	3	2	0
8	1	2	1	4	0	1	4	1	0
9	2	0	0	0	1	0	2	0	0
10	0	0	0	0	0	0	0	0	0
11	1	0	2	3	1	1	3	1	0
12	0	1	0	1	0	0	2	0	0
13	3	0	0	3	0	0	3	0	0
14	0	1	1	1	0	1	1	0	1
15	2	0	0	2	0	0	2	0	0
16	1	0	0	1	0	0	1	0	0
17	1	0	2	1	1	2	1	3	0
18	3	1	2	4	0	2	5	2	0
19	2	2	0	3	1	0	5	0	0
20	0	0	0	0	0	0	0	0	0
21	1	1	1	3	1	0	4	0	0
22	0	0	1	1	1	0	1	1	0
23	1	1	1	2	0	1	4	0	0

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VITA

Robert Howard Hornbaker

Candidate for the Degree of

Doctor of Philosophy

Thesis: A NEAR-OPTIMAL DYNAMIC PROGRAMMING MODEL FOR ON-FARM IRRIGATION SCHEDULING OF GRAIN SORGHUM IN THE OKLAHOMA PANHANDLE

Major Field: Agricultural Economics

Biographical:

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