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The Impact of Energy Shortages and Cost on Irrigation for the High Plains and Trans Pecos Regions of Texas

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FOREWORD

This report represents a condensation of three major studies and several small analyses. Overall, from this research project there were three Ph.D. dissertations in agricultural economics and several publications and technical papers produced. In addition, the results were used to prepare testimony for hearings with the Texas House of Representatives, Agricultural Committee and United States Senate.

The specific publications that are directly attributable to this project are available from the authors. These publications provide much greater detail on models, assumptions and results. The publications upon which this summary and research completion report is based are listed below with the complete description listed in references section.

Condra, Gary D. and Ronald D. Lacewell
Condra, Gary D., Ronald D. Lacewell, Daniel C. Hardin, Kenneth Lindsey and Robert E. Whitson
Hardin, Daniel C. and Ronald D. Lacewell
Hardin, Daniel C., Ronald D. Lacewell and James A. Petty
Knutson, R.D., Ronald D. Lacewell, et.al.
Lacewell, Ronald D.
Lacewell, Ronald D., Gary D. Condra and Brian Fish
Patton, William P. and Ronald D. Lacewell
Petty, James A., Ronald D. Lacewell, Daniel C. Hardin and Robert E. Whitson
Zavaleta, Luis, Ronald D. Lacewell and C. Robert Taylor

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This research project extended over a three year period and included several regions in Texas as well as development and application of many economic models. Due to the breadth of this work, cooperation and assistance by a very large number of individuals and organizations was essential and to them we attribute primary responsibility for success of the research.

Principally, we are deeply indebted to the Texas Water Resources Institute. Dr. J.R. Runkles, Director, provided guidance to the direction of the analyses while Mrs. Theo Doerge and Evelyn Teaff effectively carried out the responsibility of maintaining fiscal records and assuring that progress reports were submitted appropriately.

In developing and modifying models, a large number of scientists gave unselfishly of their time. We are most grateful for their contribution and a simple mention of their name is grossly insufficient. Modification of the grain sorghum plant growth model was accomplished through close cooperation with G.F. Arkin and Don Reddell. The High Plains model relied heavily on crop enterprise budgets developed by Ray Sammons and compiled by Cecil Parker as well as several hours of cooperative work with John Shipley. Bill Lyle provided the idea and a working model of a new irrigation distribution system.

Ms. Ann Bell and Wayne Wyatt were most helpful in providing High Plains aquifer characteristics and expected well yields. The Trans Pecos model required substantial producer participation and we are extremely grateful to the St. Lawrence Cotton Growers Association for their important contribution.

The contribution by Bob Whitson in development of the High Plains and Trans Pecos models led to vastly improved analyses. Similarly, Bob Taylor provided valuable assistance in development of the grain sorghum model. To Dr. Whitson and Dr. Taylor we express a special acknowledgement.

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Introduction

The High Plains and Trans Pecos regions of Texas are semi-arid crop production regions located in the western part of the state. Relatively low levels of rainfall are supplemented by irrigation from groundwater supplies. These regions produced 51 percent of the cotton, 42 precent of the grain sorghum, and 48 percent of the wheat produced in Texas in 1974 (Texas Crop and Livestock Reporting Service). Considering only irrigated production these percentages were 75, 85, and 91 percent of Texas irrigated crop production for cotton, grain sorghum and wheat respectively. The importance of the High Plains and Trans Pecos regions to Texas crop production are not limited to these three crops, however, these statistics do serve to illustrate the significance of these regions in the Texas agricultural economy.

While it is easily seen that the majority of irrigated production (for the crops mentioned) in Texas occurs in these regions, it should be noted that the importance of irrigation in the High Plains and Trans Pecos regional economies is much greater than these statistics show. On the High Plains 86 percent of the cotton, 90 percent of the grain sorghum, and 75 percent of the wheat produced in 1974 was harvested from irrigated acreage. Rainfall is somewhat less in the Trans Pecos region and 100 percent of the production of these crops was under irrigation (Texas Crop and Livestock Reporting Service). More than 60 percent of the value of agricultural crops in Texas is produced on irrigated land (Knutson, et.al.). Thus, the crop production of these regions is vitally important to the Texas and respective regional economies. Crop yields are heavily dependent on groundwater irrigation and extremely sensitive to any factor which may affect the availability or cost of irrigation water.

Availability and price of fuel used in pumping groundwater are the critical factors which directly affect the availability and cost of irrigation water. About 39 percent of the energy used in Texas agriculture in 1973 was utilized in pumping water, compared to 18 percent used in machinery operations. Of this irrigation fuel, 76 percent was natural gas, the majority of which was consumed in the High Plains (Coble and LePori). Current supplies and reserves of natural gas have reached critically low levels in recent years and producers in the High Plains and Trans Pecos regions are faced with possible curtailments of, and certain price increases for their irrigation fuel (Patton and Lacewell).

The threat of possible curtailment of fuel supplies during the irrigation season imposes greatly increased risk to irrigated crop production since curtailment of natural gas supplies during a critical water use period would significantly reduce yields (Lacewell). This threat would also increase financial risk and restrict availability of credit.

Continued price increases for natural gas will increase costs of pumping irrigation water and hence the costs of irrigated crop production (Patton and Lacewell). The Ogalalla aquifer underlying the High Plains and many of the alluvium aquifers underlying the Trans Pecos are exhaustible; i.e., there is a negligible recharge from percolation and other sources. Therefore, even with unchanged natural gas prices, these groundwater supplies are being "economically" exhausted over time as pumping depth increases. Increases in fuel prices will lead to reduced groundwater pumpage and result in less groundwater being economically recoverable. Although life of the physical supply will be exhausted, a greater quantity of groundwater will be economically unrecoverable for irrigation without significant product price increases.

Objectives

The purpose of this report is to report on a research program designed to develop estimates of the response to limited fuel, to increased fuel prices and new technology in the High Plains and Trans Pecos regions. The general objective of this study was to estimate the impact of curtailment and increased price levels for natural gas on irrigation levels and net incomes to producers in the High Plains and Trans Pecos regions of Texas. The specific objectives are as follows:

Objective 1 -- To estimate the impact of natural gas curtailments of given duration in selected periods of time on crop yields and net returns in the High Plains region.

Objective 2 -- To estimate the impact of natural gas price increases in the High Plains and Trans Pecos regions on irrigated acreage and groundwater use, cropping patterns and output levels, and net income to the producers.

Objective 3 -- To evaluate the net benefits of increasing pump efficiencies on the High Plains under selected levels of natural gas prices.

Objective 4 -- To evaluate the net benefits of improving soil and irrigation management practices in the Trans Pecos under selected levels of natural gas prices.

Procedure

Since this report is a synthesis of several studies, different models and methods of analysis were employed. There are basically three different models used. In addition some simple budgeting and break-even analysis was used to generate some values in a timely manner as the regions experienced an economic or natural crisis of one type or another. This section is separated into four sections, one for each model and a brief discussion of other methods used.

High Plains Model

The High Plains Model was used to evaluate the expected effect of alternative crop and input prices (particularly increasing natural gas price) and new technology on farmer net returns, present value of the groundwater supply and rate of irrigation water use (Petty, Lacewell, Hardin and Whitson). The High Plains Model is a linear programming (LP) model of a typical farm situation on the Texas High Plains. The model includes the major crops in the area (cotton, corn, grain sorghum, soybeans and wheat) under all applicable dryland and irrigation options. A total of 65 production activities are included. Both furrow and center pivot sprinkler systems are included.

Crop enterprise budgets developed by the area economists of the Texas Agricultural Extension Service for the 1978 crop year were the basis for developing the model coefficients. Yield data for alternative irrigation levels were taken from statistical production functions estimated for the area (Shipley 1977a, Shipley 1977b).

The LP model divides water availability into critical periods; the limits established with the maximum amount that could be pumped in each time period, based on well yield in gallons per minute and the average number of days in each period not used for well repairs and maintenance.

The model can be used for an annual evaluation or a temporal analysis. For a temporal analysis, the LP model is established in a recursive framework. An extension of linear programming is utilized which consolidates a Fortran program with the LP model. The Fortran model functions as a subroutine which modifies the LP model for subsequent solutions. The Fortran model in this analysis performs the following tasks:

1) Calculates the decrease in saturated thickness and associated increase in pumping lift based on the amount of water withdrawn in the previous year.
2) Calculates the change in well yields based on the change in saturated thickness.
3) Calculates the change in natural gas required to pump an acre foot of water based on the change in pumping lift.
4) Calculates the maximum irrigation water availability in each time period based on the adjusted well yield.
5) Calculates the present value of net returns to the farm plan.
6) Modifies the LP tableau with the new water availabilities and natural gas requirements.

The equations used in the Fortran program are as follows (sources of equations or data used to develop equations are given in parentheses, where applicable):

AQUIFER DEPLETION:

$$D = W_{t-1}/(.15 * CA)$$

where:

D = decline in static water level of the aquifer
W_{t-1} = acre-feet of water pumped in the previous year
CA = acres contributing to the aquifer (includes non-cultivated land and dryland)

WELL YIELD:

$$GPM_t = GPM_0 \text{ if } ST_t/ST_0 \geq .83667$$

else:

$$GPM_t = 1.14*(ST_t/ST_0)^{0.71} * GPM_0$$

where:

GPM = well yield in gallons per minute
ST = saturated thickness

NATURAL GAS (Kletke, Harris and Mapp):

$$NG_t = .0623\ PSI + .0272L_t$$

where:

NG = natural gas required to pump one acre-foot of water
PSI = water pressure required in pounds per square inch
L_t = pumping lift

WATER AVAILABILITY:

$$M = .004*GPM_t*T$$

where:

M = maximum acre-feet of water that can be pumped in a specified period by one well
T = days available for pumping in a specified water period

In order to estimate returns to the groundwater resource, it is first necessary to establish returns to land and management. The linear programming model was applied with only dryland crop alternatives. This provided a dryland cropping pattern and an estimate of annual net returns. These annual dryland net returns were assumed to be constant over the period of the analysis. Thus for the temporal analysis, returns to land and management were defined as the discounted stream of dryland net returns over the 25 year planning horizon.

Trans Pecos Model

This model generates estimates of the potential survival and profitability of an irrigation farm in the Trans Pecos region of Texas by simulating the planning and operation of a farm under conditions of stochastic prices and yields (Condra, Lacewell, Hardin, Lindsey and Whitson). Multiple time periods are simulated recursively to consider the effects of outcomes in one time period upon another and the effects of timing of both favorable and unfavorable outcomes. The dynamic nature of the model also allows the analysis of cash flows, lumpiness of input purchases, and beginning equity position as they affect the survival and profitability of the farm.

The model consists of basically four components where each is one step in the model operation. The process is initiated by providing the beginning farm situation and proceeds, as follows: (1) A farm enterprise plan is developed, based on expected crop prices and yields. The farm enterprise plan is developed by a linear programming model constrained by a risk element. This type model is typically termed a MOTAD model (Hazell). The expected prices and yields going into the MOTAD model were estimated from an adaptive expectations model since it represents a reasonable description of the process used by farmers and ranchers (Fisher and Tanner). The expectation model is a basic Nerlove model and was applied by Chien and Bradford in their sequential model of the farm firm growth process. The price expectation model was also augmented with an exponential smoothing trend model to overcome the tendency of the Nerlove model to lag a continuing trend (Brown and Meyer; Chien and Bradford). (2) Probabilistic ('actual') prices and yields are generated. Random prices and yields are drawn from a triangular distribution to represent actual outcomes for these variables in analysis of economic viability of the farm. The triangular distribution includes an estimate for minimum, most likely and maximum value for price or yield. For prices, inflation was included, hence the triangular distribution followed the expected price trend for a specified inflation scenario. (3) The operation of the farm is simulated (using 'actual' prices and yields), including evaluation of the financial outcome of the plan, payment of fixed obligations, determination of year-end financial position, and replacement of machinery. This process includes (a) implementing the farm plan, (b) replacing machinery, (c) paying fixed obligations, (d) developing financial statements, and (e) evaluating credit capacity. Credit capacity is evaluated based on the current financial position, the previous year's financial position, and operating loan repayment performance. If sufficient cash is not available to fully repay the operating loan after fixed obligations are met, the operating loan carry over for the previous year is examined. Credit is extended if the operating loan carry over from the previous year has decreased. If the operating loan has not decreased, then credit will be extended if net worth has increased from the previous year by more than the increase in operating loan carry over. (4) The planning situation is updated to reflect adjustments in expected prices and yields (based on 'actual' prices and yields), changes in resource availabilities, and credit restrictions. The process then returns to Step 1 to repeat the simulation for the next year's farm plan and operation. This simulation process is carried out by four sub-models: (1) planning, (2) price-yield, (3) financial-accounting, and (4) update.

Grain Sorghum Simulation Model

The purpose of this model was to estimate optimum irrigation strategies and project expected effects of stochastic irrigation curtailments to grain sorghum on the Texas High Plains (Zavaleta, Lacewell and Taylor). To generate these estimates, three major components can be identified. (1) A biological grain sorghum growth model developed by Arkin et.al. that constitutes a practical approach for calculating the daily growth of a grain sorghum crop growing under field conditions. The appearance of leaves, the rate at which they enlarge and the timing of these events are growth characteristics developed in the model. The physical and physiological processes of light interception, photosynthesis, respiration and water use were independently modeled and used as submodels in the growth simulation model. The estimated growth is for an "average" plant growing in a field. The total grain accumulated is the result of the product between the grain weight of the average plant and the population. (2) The use of Arkin's model requires, however, daily information on meteorological variables such as maximum and minimum temperature of the day, the amount of precipitation occurred and the amount of langley units as a measure for solar radiation. The model to estimate the conditional probability functions were developed by Rockwell for each of the above variables and used to generate a series of weather patterns. The simultaneous use of the sorghum growth and weather models allowed forecasts of conditional probability distributions of the yields. (3) Since the focus of the research is on the economic optimization of yields, prices of the resources used and of the output were introduced in the model and designed to the extent of reflecting decision criteria that would be followed by an economic agent in the actual world. At this stage of development, the simulation model constitutes a technique of performing sampling experiments of the system it represents. The different results obtained from the iterative process to which the model is submitted reflect not necessarily optimal outcomes but the trajectory qualified by the initial conditions. At each decision stage, the optimal value of the remaining control variables is iteratively searched.

The practical importance of iterative solution techniques should by no means be overlooked. They often offer the simplest, most direct alternatives for obtaining solutions, but their greatest achievement possibly lies in establishing trade-off points between the difficulty of implementation and the speed of convergence. Though many algorithms exist to obtain optimum points, there is a fundamental underlying structure for almost all of them: Beginning at an initial point determines--according to a fixed rule--the direction of movement and proceeds to locate, in the predetermined direction, a (relative) optimum of the objective function on that line. Once located at the new point a new direction is determined and the procedure is repeated. The line search--or process of finding the optimal point on a given line--as its name indicates, allows the finding of the optimal point for those nonlinear functions that cannot be analytically optimized. An extended number of approaches to this important phase of optimization can be cited: Fibonacci, the Golden Section, Newton's method, False Position, cubic and quadratic fit, steepest descent, coordinate descent methods, conjugate direction methods, etc., of which the sophistication of implementation varies directly to the speed of convergence and the selection of the method depends on the particularities of each problem analyzed. In the specific case of the problem faced in this study, professional judgement and ciphering facilities lead to the use of the theory involved in quasi-Newton methods.

Budgeting and Breakeven Analysis

With changes in methods of production as well as prices of inputs and products, there was a need to develop new crop enterprise budgets for the new conditions (Condra, Lindsey and Neeb; Sprott, Lacewell, Niles, Walker and Gannaway). In this case, standard procedures were followed to account for cash costs (variable), harvesting costs and fixed costs (land, insurance, taxes, management, etc.). With detailed per acre crop enterprise budgets available, alternative systems and prices could be compared to develop cursory economic implications.

Alternatively, the question of how much a farmer could pay for natural gas arose (Hardin and Lacewell; Condra and Lacewell). To determine a breakeven price of natural gas (amount that could be paid), the basic principle adhered to was to allocate a return to all factors of production except irrigation water. This means fixed and variable costs are included. For irrigation pumping costs, all costs except fuel were included. This left a residual to water which would be available to pay for natural gas.

By dividing quantity of gas required to irrigate an acre into the above residual, an estimate of the price where natural gas costs make irrigation and dryland production equally profitable is obtained, i.e., the farmer makes the same profit whether he irrigates or not.

An alternative case is where natural gas price increased 450% in the Trans Pecos. Costs of production with the higher gas price was estimated. This cost of production was divided by expected yield to determine the breakeven price of each crop; i.e., the price per unit for each crop required to just exactly cover costs of production. This breakeven price can be compared to market price to provide an indication of economic viability of crop production in a region.

Results

Again it is emphasized that this report is an abstraction of several detailed reports. This section is organized into three sections including expected effects and implications of (1) natural gas or irrigation fuel curtailment, (2) natural gas price increases with alternative crop and other input prices and (3) new technology to improve efficiency of irrigation water.

Irrigation Fuel Curtailment

A regional study which examined the impacts of fuel shortages in the Southern High Plains used a linear programming model (Casey, Lacewell and Jones). Fuel availability was parametrically changed to estimate the effect on area output, net returns and cropping patterns.

Fuel shortages on the Southern High Plains of Texas would have different effects on agricultural output and net returns depending on the nature of the shortage (in-season, at harvest or for irrigation). Diesel fuel shortages during the growing season and/or at harvest up to about 15 percent would cause little effect on output, given that producers adopt a reduced tillage production alternative during the growing season.

The results indicate that a 20 percent reduction in diesel fuel requirements during the growing season could force all the acres of the High Plains to shift to reduced tillage practices. Due to higher costs of herbicides required to maintain yields, this would result in a $14 million reduction in net terms.

A diesel fuel restriction during the harvest period forces the producers to delay harvest beyond the normal or optimum period. A harvest delay is also associated with decline in yield for grain sorghum and cotton and quality decline for cotton. However, fuel shortages during the period when the crop is first ready to harvest cause, in an average year, a relatively small reduction in output if harvest fuel is available before the end of the calendar year.

Irrigation fuel shortages cause the most serious reductions in output in net returns. This suggests that natural gas for irrigation is the most critical fuel to agriculture in the Texas High Plains. With any reduction in natural gas available for irrigation there is a direct impact on output since fewer irrigations are applied or cropland is forced from irrigated to dryland production.

Results indicate that if natural gas was restricted, grain sorghum would initially shift from irrigated to dryland production in the hardland soils. The next adjustment with more stringent shortages would cause cotton production to shift to lower irrigation levels. Basically, for each 5 percent reduction in natural gas supply, irrigated acres decline 5 percent and producer net returns decline around 4 percent.

The limitation of the Casey, et.al. study is that it assumes the producer knows at the beginning of the season of the curtailment and plans accordingly. More likely, a fuel curtailment would be unanticipated. The timing of an unexpected irrigation fuel curtailment is critical.

Zavaleta, Lacewell and Taylor estimated the expected effect on yield and net returns of an irrigation fuel curtailment. By using the modified sorghum plant growth simulation model, thirty alternative simulations (30 simulated years) were included for each analysis to obtain an approximation of the expected range in yields and net returns. For each year, optimal irrigation strategies were planned ahead, evaluated and reformulated at predetermined periods to obtain maximum net revenues from the production of grain sorghum.

Five curtailment periods of 10 days, three periods of 20 days and two periods of a 30 day curtailment were simulated to analyze the effect that a shortage of natural gas due to institutional factors could have on net revenues received by farmers and on the levels of production obtained. The expected effect on per acre yield is presented in Table 1.

The effect of a 10 day irrigation curtailment has essentially no impact on yield or net returns. This is because the analysis is based on eight irrigation periods and that the producer has excellent control over the irrigation water. The analytical model assures a safe profile of moisture in the soil, hence, the ten day curtailment period creates no problem. Exactly at the end of the curtailment period, extra water is applied to return to the safe soil moisture position.

Due to well limitations most farmers do not meet optimally the plants' water needs. As such, the absolute yields are higher than average.

Table 1. Simulated effect on grain sorghum per acre yields associated with alternative periods of irrigation fuel curtailments: Texas High Plains.[a]

Curtailment[b] Period	Yield (cwt/acre)			
	Average	High	Low	$S_{\bar{x}}$[c]
No Curtailment	89.9	99.3	79.9	5.06
Ten day curtailment				
20-30	89.3	98.7	78.8	5.23
30-40	89.7	99.2	79.4	5.08
40-50	88.3	99.1	78.6	5.88
50-60	88.9	99.0	78.6	4.89
60-70	89.3	97.3	78.4	5.17
Twenty day curtailment				
20-40	86.5	96.3	75.7	5.45
40-60	80.0	92.4	64.2	7.91
60-80	83.6	96.2	68.3	6.70
Thirty day curtailment				
20-40	77.2	92.5	56.2	9.60
40-70	72.9	91.6	56.5	9.08

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[a] Based on 30 simulations (years) per curtailment period.

[b] Curtailment period is days after plant emergence.

[c] Standard deviation is a measure of dispersion; i.e., the larger the value the wider the range of expected yields or the greater the risk and uncertainty of yield.

In addition, after a curtailment a producer cannot immediately irrigate all his land. Hence, these results underestimate the impact of curtailment. Perhaps a better interpretation of the results would be that the curtailment period refers to the days irrigation would be delayed due to an energy curtailment. Farmers do not have perfect control over irrigation nor do they have sufficient water to plan based on eight irrigation periods. Thus, an energy curtailment of only four or five days could result in a delay of a planned irrigation of several days. This means the 20 and 30 day irrigation curtailment analysis can be expected to be reasonable estimates of impact due to a fuel curtailment of only a few days.

In general, the results obtained from the 20 and 30 day irrigation curtailments indicate that during the initial stages of the plant growth curtailments would constitute a vital limitation of future yields. During those early stages adequate supplies of nutrients and water are necessary to allow the potentially maximum development of the plant. Thus, around the boot and half-bloom stages (40-70 days after emergence) moisture stress prevents complete pollination at flowering time and any severe moisture stress can result in poor head filling. An increase in risk is reflected by the range in yields and larger standard deviations of yields. Average yield due to irrigation curtailment would decline by 7 to 16 percent.

The per acre net returns given a 20 and 30 day irrigation curtailment for different periods in the growing season are presented in Table 2. The 10 day curtailments did not impact on net revenues given the farmer has complete control of irrigation water across his farm; i.e., ability to irrigate any acre at any time. The results given the 20 or 30 day curtailment are in the expected direction; i.e., large reductions in average net

Table 2. Simulated effect on grain sorghum per acre net returns associated with alternative periods of irrigation fuel curtailment: Texas High Plains.[a]

Curtailment[b] Period	Net Returns ($/acre)			
	Average	High	Low	$S_{\bar{x}}$[c]
No Curtailment	99	132	62	18
Twenty Day Curtailment				
20-40	95	130	56	19
40-60	71	119	12	30
60-80	83	136	38	25
Thirty Day Curtailment				
20-50	67	120	-10	35
40-70	50	117	-12	34

[a] Based on 30 simulations (years) per curtailment period and grain sorghum price of $4.07/cwt and natural gas price of $2.50/mcf.

[b] Curtailment period is days after emergence.

[c] Standard deviation is a measure of dispersion; i.e., the larger the value the wider the range of expected net revenues or the greater the risk and uncertainty of net revenue.

revenues, in some cases up to $50 more per acre. For all 20 and 30 day curtailments, departures from the optimal pattern meant a lower net return. These results are based on the producer adopting an optimum irrigation schedule as soon as the curtailment period is over; i.e., a new optimal pattern was adopted to apply irrigation water in every case where irrigation was planned but a curtailment took place. A subsequent 'make-up' throughout the rest of the growing season was requried to compensate the moisture stress to which the plant was exposed. In all cases, the decline in the total amount of water used was not sufficient to compensate for the losses in grain yield. This finding reveals that correct timing in applying irrigation water has a higher contributing value to net revenues than the total amount of water per se.

Briefly stated, curtailments of natural gas will, on the average, (1) reduce net revenues, and (2) reduce the grain sorghum yields albeit almost the same amount of irrigation water is used.

Again the reader is reminded that this model is based on eight irrigation periods and perfect control of irrigation over an entire farm. The estimates, therefore, apply to an advance level of technology. For current conditions, the estimates of irrigation curtailment have limited application and certainly are very conservative.

The subject of estimating the effects that fuel curtailments could have on levels of production and net returns has been addressed by several authors, so to that extent this study did not differentiate much from the previous. This study, however, introduced a new approach different to other studies; i.e., the effects of fuel curtailments were estimated considering their date of appearance as being unknown to the decision maker. At every decision point the economic agent formulated a strategy to be followed with respect to the use of irrigation water as it would be available in the amounts required. It was expected and later confirmed that the non-availability of the resource would have different effects according to the growth stage of the plant.

Natural Gas Price Increase

The expected effect of an increase in the price of natural gas used for irrigation has been evaluated for both the Trans Pecos and High Plains. Results are based on the simple budgeting and breakeven analysis as well as application of the more sophisticated models.

Trans Pecos

The Texas Trans Pecos region has experienced one of the most dramatic price increases for natural gas in the country. The impact of this on irrigation has been estimated by Condra and is presented in several reports (Patton and Lacewell; Condra and Lacewell; Lacewell, Condra and Fish; Lacewell 1975 and 1976; and LePori and Lacewell).

Production Costs: The impact of the natural gas price increase from \$0.40 to \$1.85/per thousand cubic feet (mcf) has resulted in production costs increasing from \$30 to \$90 per acre. This amounts to a 450 percent increase in price of natural gas and translates into a 60 percent increase in the cost of irrigation. Relating these higher production costs to individual crops, a product price for each crop that would be required to exactly cover all costs of production was estimated. This is defined as the breakeven product price. The values in Table 3 show

Table 3. Increase in costs of production associated with natural gas price increase and effect on economic viability of crops irrigated: Texas Trans Pecos[a]

Crop	Unit	Water applied (acre inches)	Increased Production cost per acre dollars	Crop Prices	
				Breakeven	Recent[b] Market
Alfalfa	ton	72	92.16	102.39	52.00
Barley	bu	38	48.64	3.87	1.90
Cantaloupe	crate	24	30.72	7.04	11.10
Cotton--Pima	lb. lint	44	56.32	1.25	.95
Cotton--Upland	lb. lint	44	56.32	.77	.57
Sorghum--Forage	ton	36	46.08	14.29	12.00
Sorghum--Grain	cwt	28	35.84	6.99	3.58
Wheat	bu	24	30.72	4.52	2.80

[a] Source: Condra and Lacewell. Based on a natural gas price increase of from \$0.40 to \$1.85/mcf.

[b] Prices in mid 1978.

that all crop enterprises are returning less than the costs of production.

In terms of water pumped, producers using \$0.40/mcf natural gas incurred a cost of \$2.12 per acre inch of water pumped compared to \$3.40 per acre inch of water pumped at \$1.85/mcf for natural gas. Based on this disparity between current crop prices and prices required to breakeven, it must be concluded that the majority of the land in the Trans Pecos region will not be held in crop production activities indefinitely under the current input and output price situation.

To further investigate the economic viability of irrigated crop production in the Trans Pecos, the Trans Pecos model was applied under several different sets of crop and input price scenarios (Condra, Lacewell, Hardin, Lindsey and Whitson). The basic scenarios are shown in Table 4 and represent a base or expected situation, pessimistic situation (low) and optimistic situation (high). Results for each of these scenarios in the Trans Pecos model are mean values for 20 simulations of a 10 year period. Thus, there was considerable variation among simulations and years.

Cropping Patterns: Average farm plans for the basic Trans Pecos model under alternative future scenarios are shown in Table 5. Cotton was the primary crop for all scenarios ranging from 405.1 acres for conditions termed LOW to 573.3 acres for HIGH, or 73 to 78 percent of total crop acreage, respectively. Wheat was the next most important crop with acreage ranging from 90.0 acres (15 percent) for LOW to 103.7 acres (26 percent) for BASE. Grain sorghum comprised only 41.4 acres or 7

Table 4. Alternative Scenarios for Inflation, Energy Prices, Crop Prices and Interest Rates, 1978-87: Trans Pecos

Item	Base	Low	High
	---percent---		
Inflation	7	4	10
Energy Price Increase	10	10	10
Crop Price Increase			
Cotton	7.5	3.4	12.0
Sorghum	7.5	3.4	11.8
Wheat	7.5	4.0	13.6
Short Term Interest	9.0	6.0	12.0

Table 5 . Cropping Patterns for Alternative Scenarios, Trans Pecos; 1978-87.

Item	Units	Scenario		
		Base	Low	High
Cotton Acreage:				
Mean	acres	460.3	405.1	573.3
Trend[a]	percent	5.6	-14.2	-0-
Wheat Acreage:				
Mean	acres	103.7	90.0	103.2
Trend[a]	percent	-20.5	-8.9	-13.6
Grain Sorghum Acreage:				
Mean	acres	41.4	61.6	8.4
Trend[a]	percent	21.7	0.8	30.0
Total Crop Acreage[b]:				
Mean	acres	605.4	556.7	684.9
Trend[a]	percent	0.5	-11.6	-1.8
Dryland Acreage[b]:				
Mean	acres	-0-	-0-	-0-
Trend[a]	percent	-0-	-0-	-0-
Irrigated Acreage[b]:				
Mean	acres	605.4	556.7	684.9
Trend[a]	percent	0.5	-11.6	-1.8

[a] Trend estimated as continuous rate of change

[b] Does not include set-aside acreage

percent for BASE at the minimum and 61.6 acres or 11 percent for LOW at the maximum. Total crop acreage (and irrigated acreage) varied from a low of 556.7 acres for LOW to 684.9 acres for HIGH.

Comparing LOW (worst case), BASE (most likely), and HIGH (best case), total crop acreage and the acreage of cotton and wheat increased in response to higher levels of assumed crop prices. However, grain sorghum acreage decreased in response to increases in the overall level of crop prices. Results from other scenarios indicate that the competitive positions of the alternative crops are not only sensitive to the absolute levels of crop prices, but to the relationship between input price and crop price increases, as well.

Looking at trends in crop acreage within scenarios, total crop acreage was relatively stable in all applications except LOW where it decreased 11.6 percent annually. Cotton maintained or increased its share of crop acreage in BASE and HIGH. Wheat maintained or increased its share in LOW, while grain sorghum maintained or increased its share in BASE, LOW, and HIGH. Thus the relative importance of either cotton or wheat in the farm plan tended to increase depending on the scenario, but both did not increase in relative importance within a given scenario.

Farm Survival: Farm survival in this study was equated with solvency, thus the simulated farm "survived" as long as it had or could borrow sufficient resources to operate and meet fixed obligations. Selected measures of farm survival for the model under alternative scenarios are shown in Table 6. On the average the Coyanosa farm survived about 5 years for all scenarios except the HIGH scenario where the average life

Table 6. Selected Measures of Farm Survival for Alternative Scenarios, Trans Pecos, 1978-87.[a]

Item	Units	Scenario		
		Base	Low	High
Years of Survival:				
Mean	years	4.6[b]	5.6[b]	7.9
Std. Dev.	years	3.0	3.0	3.4
Probability of Surviving:				
2 years	percent	100.0	100.0	95.0
3 years	percent	75.0	80.0	80.0
4 years	percent	50.0	65.0	80.0
5 years	percent	35.0	55.0	80.0
6 years	percent	20.0	45.0	75.0
7 years	percent	20.0	40.0	75.0
8 years	percent	20.0	35.0	70.0
9 years	percent	20.0	25.0	65.0
10 years	percent	20.0	15.0	65.0

[a] This analysis is based on a new farm operation in the Trans Pecos where beginning equity is 25%, the producer is purchasing 320 acres and renting 640 acres on a traditional crop share basis. Adjustment in beginning equity and the purchase-rental assumption would significantly affect the estimates.

[b] Means followed by the same letter were not significantly different at the 5% level using analysis of variance and Duncan's Multiple Range Test.

was 7.9 years. The difference between the average lives of the other scenarios were not statistically significant even though the values ranged from 4.6 years for BASE to 5.6 years for LOW. This situation can be explained by simply examining the high degree of dispersion in terms of the standard deviations.

The probabilities of surviving a given number of years shown in Table 6 provide more information on the effects of alternative scenarios on farm survival. These probabilities are based on the 20 simulations of each 10 year period for each scenario. Thus a 50 percent probability of surviving eight years in only 10 of the 20 simulations. Survival rate of the Trans Pecos farm for the entire 10 year period ranged from 15 percent under the LOW scenario to 65 percent under the HIGH scenario. However, over one-half the insolvencies in all scenarios occurred within the first five years of the period. Therefore caution should be used in applying these results directly as a probability of survival, because the failure pattern suggests that changes in the assumed equity position of the farmer would likely change the average life and influence the probability of survival for the 10 year period.

Farm Profitability: Selected measures of profitability and growth potential for the Trans Pecos model are shown in Table 7. The internal rate of return was chosen as the primary measure of profitability for this study. The internal rate of return was negative for BASE (-12.0) and LOW (-22.6). However, there was no significant difference between the rates of return for these scenarios. The standard deviations, the maximums, and minimums also indicate the degree of dispersion around

Table 7. Selected Measures of Profitability and Growth Potential for Alternative Scenarios, Trans Pecos, 1978-87.[a]

Item	Units	Scenario		
		Base	Low	High
<u>Internal Rate of Return:</u>				
Mean	percent	-12.0[b]	-22.6[b]	36.8
Std. Dev.	percent	29.2	29.5	47.3
Maximum	percent	28.5	30.1	128.5
Minimum	percent	-114.8	-100.0	-37.8
<u>Net Farm Income:</u>				
Mean	$/year	25,505	1,040	108,717
Trend[c]	$/year	4,049	-7,593	17,144

[a] This analysis is based on a new farm operation in the Trans Pecos where beginning equity is 25%, the producer is purchasing 320 acres and renting 640 acres on a traditional crop share basis. Adjustment in beginning equity and the purchase-rental assumption would significantly affect the estimates.

[b] Means followed by the same letter were not significantly different at the 5% level using analysis of variance and Duncan's Multiple Range Test. Means for net farm income were not tested.

[c] Linear trend.

the mean rates of return. Scenario HIGH had a positive 36.8 percent annual rate of return, but the coefficient of variation (1.285) represents a large variation in rates of return.

Net farm income for HIGH was over four times as large as that of BASE and 100 times that of LOW. The trends on net farm income are positive for BASE, whereas the trend was negative for LOW. Therefore, the discounting process tended to offset the growing divergence in later years between the net farm incomes of BASE and LOW.

The HIGH scenario provides a fairly good opportunity for growth with an expected rate of return of 36.8 percent and increasing net income. When adjusted for inflation, the real rate of return is still 26.8 percent (36.8 - 10.0) and the trend in net income is greater than the rate of inflation indicating that the real rate of return is increasing through time. The BASE scenario provides marginal opportunities for growth with negative, but increasing rates of return. The LOW scenario provides little opportunity for growth with negative, decreasing rates of return.

Effect of Risk Aversion: In addition to the basic Trans Pecos model which was designed to plan around very risky situations two other levels of risk aversion were specified for model applications; i.e., a higher risk-aversion model and a model which includes no risk-aversion restraint (i.e. a profit-maximizing model). As the level of risk-aversion decreased, total crop acreage increased from 509.4 acres to 684.9 acres. Cotton acreage increased proportionately more from 287.0 acres to 573.3 acres or nearly double. Grain sorghum and wheat acreage both decline in terms of absolute acreage and share of total crop acreage in response to the decreased risk-aversion. These results indicate that total crop acreage tends to increase and cotton tends to replace grain crops as the level of risk-aversion is reduced. Total crop acreage tends to increase because the less risk-averse producer is more willing to purchase resources (e.g. labor) to plant more acres.

The rate of farm survival also increased in response to decreased risk-aversion even though the average years of survival were not significantly different at 4.6 and 3.1 years for basic model and high risk aversion, respectively. However, the average years of survival for the profit-maximizing model were increased significantly to 8.3 years. The probability of survival was also greater for the profit maximizing solution in all years from three to ten.

The internal rate of return increased as the level of risk-aversion was decreased; however, the difference between the basic model and higher aversion as well as profit maximizing were not significant. Dispersion of the rates of return also increased as the level of risk-aversion was decreased. Net farm income increased from -$7,048 for the highest level of risk aversion to $31,433 for the profit maximizing solution.

It was expected that the rate of return and net farm income would increase with decreased risk-aversion. It was also expected that the dispersion around the mean would increase for rate of return in response to lower levels of risk-aversion. These hypotheses were borne out in results just presented. However, it was expected that the rate of survival would be higher for increased levels of risk-aversion — which was not the case. Instead, the profit maximizing results show a greatly increased rate of survival at 55 percent compared to zero for the high level of risk aversion and 20 percent for the basic model. The explanation for these results lies in the effect of increased risk-aversion on net income. The higher level of risk-aversion reduced annual net farm income to a point which guaranteed financial disaster over time as equity was eroded and fixed obligations could not be met.

Effect of Tenure: To evaluate effect of tenure on the Trans Pecos farm, the basic model with the farmer purchasing 320 acres and renting 640 acres was compared to a farmer renting 960 acres and a farmer purchasing 960 acres. Total crop acreage was highest under the straight owner situation and lowest under the straight renter situation. Wheat and grain sorghum acreage were also highest under the owner situation and lowest under the renter. However, cotton acreage was lowest under the owner-renter situation and highest under the renter situation. Cotton acreage as a share of total crop acreage was relatively stable or increasing in all situations. The percentage of wheat acreage in the farm plan was declining in all situations, and the share of grain sorghum acreage was relatively stable or increasing in all situations except the owner situation.

The average years of survival for combination renter-owner and renter only were not significantly different at 4.6 and 4.75 years respectively. The owner situation was considerably higher at 7.7 years. Likewise, the probabilities of surviving for a given number of years were similar for renter-owner and renter only. The rate of survival for the 10 year period was 20 percent for renter-owner and 25 percent for renter only. The rate of survival for owner only was much higher at 65 percent for the 10 year period. In fact, all the failures under the straight owner situation occurred within the first four years.

Internal rates of return ranged from -25.4 percent for the straight renter to 8.7 percent for the straight owner. The owner-renter situation was intermediate with -12.0 percent. Net farm income also ranked in the same order with the straight owner net farm income almost twice as large as that of the owner-renter or straight renter.

These results suggest that the typical crop-share rental arrangements are not viable. Total acreage available was not planted in either the renter or the renter-owner situations. On the average, the straight renter planted 75 percent (including set-aside acreage) of total acreage available and the owner-renter planted only 74 percent. The owner, however, planted 97 percent of the available acreage. In terms of the rental arragements which were analyzed, the ownership tenure situation was much more profitable than either of the situations involving rental. Alternative rental agreements were not analyzed, thus these results may not hold for different rental arrangements.

Growth potential is good for the straight owner situation since rate of return is positive and net farm income is healthy with an upward trend. Net farm income for the straight renter situation and the owner-renter situation is trending upward, but from a much lower level than the owner situation. However, the owner has additional land principal payments which must be made from net farm income. Therefore, the difference in cash flow available for growth are not as great as they appear for the different tenure situations. The negative rates of return for the straight renter and owner-renter situations do not indicate a very great growth potential.

High Plains

The High Plains has been the focus of several studies on expected effect of an increasing natural gas price. For example, the breakeven analysis by Hardin and Lacewell provides some general implications.

Producers' ability to pay for natural gas is extremely sensitive to crop price, particularly in the case of cotton. In addition, given current prices for crops and natural gas, there are economic incentives for some producers of corn and grain sorghum to shift to dryland production, to shift to another crop, or to stop production altogether although a very small change in product and/or natural gas price could alter the situation for some.

Among the important implications of the Hardin and Lacewell paper are that as an input price (natural gas for example) begins to increase, the impact is extremely varied. The owner-operator, although he can afford to pay relatively high prices for an input or inputs, is at the same time losing equity in either his land or water. Returns to water are being diverted from the owner of the water resource to gas suppliers. This means value of the water is reduced which will impact on land values.

Renters and land purchasers are much more vulnerable than land owners. An increasing price for an input can rather quickly place them in a position of unprofitable production, hence land payment default. This implies that land will not quickly go out of irrigation due to higher natural gas prices. Rather, there is (1) an incentive to reduce levels of irrigation (2) downward pressure on irrigated land values and (3) likely shifts in cropping patterns and agricultural producers. The share renter and land purchaser may be forced out of production or into the employment of an owner-operator. It is these internal shifts that are going to be the most important and that need much more emphasis from researchers. The following economic discussion is directed to application of economic models of the Texas High Plains for the region, a typical farm firm and finally grain sorghum.

Regional Implications: A linear programming model was used for the analysis of rising energy prices on the High Plains. Details of the model and several of its applications to particular problems is presented in Lacewell (1976); Lacewell, Condra and Fish; LePori and Lacewell; Lacewell and Condra; and Condra, Lacewell, Sprott and Adams.

This analysis is based on model results evolving from parametrically increasing the price of natural gas. Two sets of crop prices were used. They included a 1971-74 (48 month) unweighted average for the High Plains and crop prices that prevailed in early 1976. This provides two sets of prices which provide an indication of model sensitivity.

The 1971-74 average prices used were corn at $1.95 per bu., cotton at $0.31 per lb., grain sorghum at $3.10 per cwt., soybeans at $4.25 per bu., and wheat at $2.60 per bu. The early 1976 projections were corn at $2.70 per bu., cotton at $0.42 per lb., grain sorghum at $4.25

per cwt., soybeans at $4.50 per bu., and wheat at $3.75 per bu. Only single-level irrigated enterprises were considered for corn and soybeans, however, alternatives for the other three crops include dryland production and different levels of irrigation. It has been assumed that all irrigated enterprises are under a furrow irrigation system and typical management applies to all crop enterprises.

Results from the analysis using a $15 per acre land change and no charge against the water resource beyond non-fuel pumping costs indicate expected regional agricultural production adjustments due to natural gas price increases. Table 8 shows producer returns to water, management and risk, irrigated acres, and crop output for the 1971-74 average crop prices. These crop prices are relatively low compared to current prices, hence they represent a lower bound.

As the natural gas price rises from $0.80 to $2.12/mcf, net returns to producers decline $39.5 million compared to those at the $0.80 natural gas price. In addition, irrigated acres decline 15 percent with cotton going completely out of production.

Shifts continue to occur up to a natural gas price of $4.67/mcf where all production is dryland and net returns are $32.4 million. This is compared to net returns of $99 million at an $0.80 natural gas price.

This analysis indicates that at a natural gas price of about $2.50/mcf important shifts begin occurring rapidly in irrigated acreage, producer net returns, and agricultural output, given the 1971-74 average crop prices.

To consider the effect of crop price, a set of prices was also

Table 8. Expected Crop Output, Irrigated Acreage and Producer Net Returns for Alternative Natural Gas Prices, Texas High Plains[a]

Item	Unit	Price of Natural Gas per 1000 cubic feet								
		0.00	0.80	2.12	2.47	2.80	3.00	3.37	3.82	4.67
		- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	-1,000,000-	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -
Net Returns[b]	dol.	129.9	99.0	59.5	49.0	40.7	38.0	35.8	33.3	32.4
Irrigated Acres[c]	ac.	2.6	2.6	2.6	2.2	1.3	0.5	0.5	0.3	0.0
Crop Output										
Corn	bu.	180.8	148.9	115.2	115.2	23.3	23.3	23.3	0.0	0.0
Cotton	lb.	203.5	203.5	203.5	0.0	0.0	0.0	0.0	0.0	0.0
Grain Sorghum	cwt	29.3	29.3	40.0	40.0	40.0	12.0	12.0	12.0	15.3
Soybeans	bu.	0.9	11.1	11.1	11.1	11.1	11.1	8.7	8.7	0.0
Wheat	bu.	12.1	12.1	16.7	16.7	29.3	29.3	30.3	30.3	30.3

[a] Source: Lacewell, Condra and Fish.
Based on a per acre $15 charge for land and no charge for water on acres irrigated. Crop prices are 1971-74 average and are cotton $0.31/lb., cottonseed $100/ton, wheat $2.60/bu., corn $1.95/bu., soybeans $4.27/bu., and grain sorghum $3.10/cwt.

[b] Net returns are to management, water and risk.

[c] Total land available is 3.7 million acres of which 2.6 million are irrigable.

used that represent late 1975 and early 1976 levels. The results using the 1976 planning price levels for crops are presented in Table 9. With the higher crop prices, a much different picture evolves. Using a natural gas price of $1.30/mcf as a base (since it is the approximate current price in the area), producer returns to water, management and risk are $289.6 million with 2.6 million acres irrigated.

At a natural gas price of $5.46, net returns decline 45 percent, and irrigated acreage declines slightly as soybeans go out of production. The next major adjustment is near a natural gas price of $7.00, at which irrigated acreage declines to 2 million and net returns decline to $116 million (a 60 percent reduction compared to a $1.30 natural gas price). Grain sorghum and cotton production are also declining.

Irrigated production ceases at $10/mcf natural gas. Returns to management and risk are $87.6 million and cotton, grain sorghum and wheat are produced dryland. It is at this point that returns to water have been reduced to zero.

The results presented in Table 9 suggest that at the 1976 planning price level for crops, the Texas High Plains will continue to be a major irrigated region, even with rather dramatic increases in the price of natural gas. This is a regional conclusion, however, a deficiency of this analysis is the lack of consideration of internal adjustments that have little immediate effect on output but have significant implications for local farmers, financial institutions, suppliers and communities.

Table 9. Expected Crop Output, Irrigated Acreage and Producer Net Returns for Alternative Natural Gas Prices, Texas High Plains[a]

Item	Unit	Price of Natural Gas per 1000 cubic feet										
		0.00	0.38	1.25	1.30	5.46	6.09	6.94	7.63	7.79	8.40	10.12
		- - - - - - - - - - - - - - - - - - 1,000,000- - - - - - - - - - - - - - - - - - -										
Net Returns[b]	dol.	331.8	319.0	291.0	289.6	160.5	141.1	116.2	99.3	95.9	92.4	87.6
Irrigated Acres[c]	ac.	2.6	2.6	2.6	2.6	2.5	2.5	2.1	1.6	0.4	0.2	0.0
Crop Output												
Corn	bu.	180.8	180.8	180.8	180.8	180.8	180.8	180.0	180.8	47.7	23.3	0.0
Cotton	lb.	96.1	203.5	203.5	203.5	203.5	173.0	173.0	61.1	61.1	61.1	61.1
Grain Sorghum	cwt	45.6	32.7	29.3	29.3	29.3	29.3	12.0	12.0	12.0	15.3	15.3
Soybeans	bu.	0.9	0.9	0.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wheat	bu.	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	30.3	30.3	30.3

[a] Source: Lacewell, Condra and Fish.
Based on a per acre $15 charge for land and no change for water on acres irrigated. Crop prices are set at levels that seem most reasonable with current information. These prices are cotton $0.42/lb., cottonseed $100/ton, wheat $3.75/bu., soybeans $4.50/bu., corn $2.70/bu., and grain sorghum $4.25/cwt.

[b] Net returns are returns to management, water and risk.

[c] Total land available is 3.7 million acres of which 2.6 million are irrigable.

Average Farm Implications: The recursive linear programming model was applied to estimate effect of natural gas price increases on a typical High Plains farm (Petty, Lacewell, Hardin and Whitson). The model was applied on a static basis (one year) to estimate change in farmer net returns due to a fuel price increase from $1.50 to $2.00 and $2.50/mcf. In addition, the recursive model was applied over a 25 year period with natural gas price increasing at $0.10 and $0.25/mcf annually. Output prices used were: corn-$2.10 bu., cotton lint-$0.48/lb., cottonseed-$80.00/ton, grain sorghum-$4.07/cwt., soybeans-$5.00/bu., wheat-$3.40/bu., wheat pasture-$12.50/AUM, light cattle-$0.56/lb., and heavy feeder cattle-$0.52/lb.

The size of the farm was set at 640 acres. The farm was analyzed with pivot sprinkler systems and alternatively with a furrow irrigation system. Three water resource situations as shown in Table 10 were included in the analysis.

Initially the model was applied for expected results in a single year comparing natural gas priced at $1.50, $2.00 and $2.50/mcf. The results on farm net returns are shown in Table 11. The Poor water resource situation is associated with a larger net return primarily because of the reduced lift and also due to increased number of wells relative to other water resource situations.

The impact of an increasing natural gas price on annual farmer net returns is greatest for farmers with the Good water resource situation, relative to the others, and on sprinkler irrigation relative to furrow. This is because the added lift and water pressure requires more energy. When natural gas price was increased from $1.50 to

Table 10. Alternative Water Resource Situation Analyzed for a Typical 640 Acre Farm on the Texas High Plains

Water Resource Situation	Saturated Thickness	Lift	Well Depth	Number of Wells
	---------------	feet	---------------	
Good	250	250	500	4
Fair	125	175	300	6
Poor	75	75	150	10

Table 11. Expected Annual Returns Above Variable Costs for Sprinkler and Furrow Irrigation on a 640 Acre Farm at Alternative Natural Gas Prices: Texas High Plains

Water Resource Situation[a]	Price of Natural Gas ($/mcf) 1.50	2.00	2.50
Good			
Sprinkler	82,063	75,350	69,453
Furrow	62,059	57,919	54,411
Fair			
Sprinkler	85,520	79,907	74,294
Furrow	66,152	62,712	59,489
Poor			
Sprinkler	90,129	85,982	81,835
Furrow	71,910	70,114	68,330

[a] See Table 10 for a description of each water resource situation.

$2.50/mcf farmer net returns were reduced $12610 (15%) and $7648 (12%) for sprinkler and furrow in a Good water situation; $11226 (13%) and $6663 (10%) for sprinkler and furrow in a Fair water situation; and $8294 (9%) and $3580 (5%) for sprinkler and furrow in a Poor water situation.

Under the sprinkler system of irrigation the use of natural gas was affected by price only in the Good water situation and for the furrow system use was only slightly decreased in response to increased price. This analysis suggests that on an annual basis the benefits of a large deep groundwater supply are offset, where natural gas is $1.50/mcf or more, by reduced lift of a relative small saturated thickness.

This same model was applied in a recursive framework over a 25 year period. Natural gas price was set at $1.50/mcf for a base run then increased at $0.10 and $0.25/mcf annually. This analysis provides a temporal evaluation of the effect of increasing natural gas price on present value of farmer net returns and particularly present value of the groundwater supply. Present value of the streams of income was calculated using a discount rate of 7.3 percent adjusted for an annual rate of inflation of 5.7 percent (Reneau, et.al.). Irrigation was terminated when the saturated thickness reached 10 feet or when irrigation became unprofitable. Model application with no irrigation (dryland) gave expected annual net returns of $17,870 for the 640 acre farm. Thus, returns to water is the difference in irrigated net returns and dryland net returns.

Table 12 presents present value of the groundwater supply, years of irrigation and ending saturated thickness for alternative gas prices

Table 12. Expected Effect on Returns to Water over Time Due to Alternative Natural Gas Prices and Water Resource Situations.

Item	Unit	Water Resource Situation[a] Good	Fair	Poor
Present Value of Groundwater				
Sprinkler				
$1.50/mcf gas price	$1,000	475.5	490.5	382.3
$0.10/mcf annual rise	$1,000	196.8	260.5	307.9
$0.25/mcf annual rise	$1,000	99.0	133.2	201.9
Furrow				
$1.50/mcf gas price	$1,000	311.1	306.7	259.7
$0.10/mcf annual rise	$1,000	138.0	192.5	230.4
$0.25/mcf annual rise	$1,000	73.3	112.2	192.2
Years of Irrigation and Ending Saturated Thickness[b]				
Sprinkler				
$1.50/mcf gas price	year(feet)	25(129.2)	25(19.6)	14(10)
$0.10/mcf annual rise	year(feet)	17(178.5)	20(39)	14(10)
$0.25/mcf annual rise	year(feet)	8(216.2)	10(82.5)	14(15)
Furrow				
$1.50/mcf gas price	year(feet)	25(132.5)	24(10)	12(10)
$0.10/mcf annual rise	year(feet)	16(180.5)	19(40.8)	12(10)
$0.25/mcf annual rise	year(feet)	8(214.5)	11(74.7)	13(10)

[a] See Table 10 for a description of each water resource situation.

[b] The analysis was for 25 years but irrigation was terminated when the saturated thickness reached 10 feet or irrigation became unprofitable. Saturated thickness is presented in parenthesis.

and water resource situations. Where years of irrigation is 25, this indicates the farm is still involved in irrigation at the end of the 25 year planning horizon.

These results indicate natural gas price has a very significant impact on farmer profit over time, with the greatest relative impact, again, being on the Good water situation and sprinkler irrigation. The present value of the groundwater is reduced 58.6 percent and 79.2 percent for sprinkler with Good water and 19.5 percent and 47.2 percent for a sprinkler with Poor water as natural gas price increases at $0.10 and $0.25/mcf per year. Furrow irrigation reductions are not as large since the energy requirements are less than for a sprinkler system (due to decreased water pressure).

In the Poor water situation, irrigation continued about 12 to 14 years regardless of the irrigation system or cost of natural gas. With a constant gas price and a $.10/mcf per year increase, physical exhaustion of the water supply is reached after 14 and 12 years, respectively, for sprinkler and furrow, while with a $.25/mcf per year increase, economic exhaustion occurs after 14 and 13 years.

The Good and Fair water situations with gas price constant operate longer than does the Poor water situation. However, when gas price increases at $.10/mcf per year, the Fair water situation operates longest; with a $.25/mcf per year increase, Poor water operates longest. Again, this is due to the much greater lift associated with Good and Fair water which in conjunction with increasing natural gas price brings about economic exhaustion much sooner.

These results indicate that increasing natural gas prices will not only decrease farmer profit but may, in fact, lead to the rapid termination of irrigation in areas having much greater lift. This means internal and structural shifts and adjustments can be expected in the face of rapidly rising natural gas prices.

Grain Sorghum Production: The grain sorghum plant growth model was applied using alternative prices of grain sorghum and natural gas to determine the expected effect on per acre yield, net returns and optimum irrigation strategy (Zavaleta, Lacewell and Taylor). Once again 30 years were simulated for each set of prices. Table 13 presents expected yield, net returns and water application. Also, a dryland alternative was included for comparison.

Expected yield with no irrigation is 14.8/cwt. However, net revenue (where fixed costs are deleted) is a negative $12.66 with a $4.07/cwt grain sorghum price. Seventy percent of the year's net returns were negative. These results are consistent with 1978 grain sorghum enterprise budget published for this region (Extension Economists-Management).

The irrigation analysis indicates the economically optimum quantity of irrigation water to apply (and in turn grain sorghum yield) is not greatly affected by increasing natural gas price from $1.50 to $2.50/mcf or grain sorghum price from $3.37 to $4.07/cwt. Yield remains very near 88/cwt and effective water use at an average of 11 to 13 inches per acre.

Thus, the big impact of input or product prices is on farmer profit. With grain sorghum priced at $4.07/cwt, the effect of increasing natural

Table 13. Effect of Alternative Grain Sorghum and Natural Gas Prices on Yield, Profit and Water Use: Texas High Plains[a]

Item	Grain Sorghum Price ($/cwt) 4.07	4.07	4.07	3.37	3.37
	Natural Gas Price ($/mcf) Dryland	1.50	2.50	1.50	2.50
Yield (cwt/acre)					
Average	14.8	87.3	89.9	87.5	87.5
High	34.3	99.3	99.3	99.3	99.3
Low	4.0	77.6	79.4	77.7	77.6
$S_{\bar{x}}$[b]	8.8	4.9	5.1	4.9	5.0
Net Returns ($/acre)					
Average	-12.66	118.25	99.36	57.03	38.48
High	61.65	159.89	132.43	90.39	72.37
Low	-53.89	89.18	61.67	31.68	14.49
$S_{\bar{x}}$[b]	33.59	16.99	17.80	13.68	13.89
Water Applied[c]					
Average	0	11.24	13.79	11.46	11.51
High	0	13.55	15.05	13.47	13.98
Low	0	8.42	11.21	8.70	8.69
$S_{\bar{x}}$[b]	0	1.10	0.80	1.13	1.23

[a] Based on 30 simulations for each set of prices.

[b] Standard deviation is a measure of dispersion; i.e., the higher the value the more instable.

[c] Water application is effective water to the root zone and does not include evaporation or percolation.

gas price from $1.50 to $2.50/mcf was an $18.89 per acre profit decline (16 percent). Similarly with a grain price of $3.37/cwt the natural gas price increase reduces expected per acre profit from $57.03 to $38.48 (33 percent). At lower product prices, the impact of an increase in the price of an input such as natural gas is relatively more severe on producer profit.

Considering a natural gas price of $1.50/mcf, the effect of sorghum price on producer profit is dramatic, as expected. An increase in the sorghum price from $3.37 to $4.07/cwt increases profit per acre from an expected $57.03 to $118.25 (a 107 percent increase). Again the reader is reminded that this model uses eight irrigation periods and allocates irrigation water optimally by assuming adequate water to irrigate any acre at any time.

Implications of New Technology

New technology in irrigated crop production may come in irrigation pumping plants, distribution systems, crop varieties, crop production systems or a combination of all. This analysis considers an improvement in distribution system efficiency and new crop production systems.

Improved Distribution Systems

Ongoing research by Lyle has sought to combine some of the more favorable aspects of both furrow and pivot sprinkler systems in a new type of sprinkler system. A mobile drip (or mobile trickle) irrigation system carries water to the field and distributes it through pipelines, like a conventional sprinkler system, yet requires approximately the same water pressure as a furrow system. It should also increase distribution efficiency through the elimination of high evaporation losses. The current stationary trickle systems are relatively labor intensive; however, the mobile system should have labor requirements approximately the same as those of conventional sprinkler systems.

The development of more efficient distribution systems will have a great short-term impact on the High Plains. It has been estimated that the elimination of just one four-inch irrigation could result in an annual savings to area farmers of 24 million dollars in fuel costs alone (Lyle). Yet the greatest benefit from increased efficiency may result from prolonging the economic life of the water supply. The purpose of the analysis herein was to estimate over a 20 year period the effect on groundwater depletion and present value of returns to groundwater for alternative irrigation distribution systems. A comparison is made between conventional sprinkler and mobile trickle systems. The analysis is based on application of the High Plains model where irrigation for a mobile trickle system was reduced 10%, 25% and 50% compared to current requirements (Hardin, Lacewell and Petty). The analysis is based on 160 acres with 150 feet of saturated thickness and one irrigation well.

In this analysis return values are an estimate of returns to water and the distribution system. Table 14 shows cropping patterns, aquifer characteristics and returns for sprinkler and the mobile trickle system where a water savings of 10 percent, 25 percent and 50 percent are assumed.

Under all distribution systems, irrigated grain sorghum is the most

Table 14. A Comparison of Sprinkler and Mobile Trickle Systems at Alternative Rates of Distribution Efficiency[a]

Item	Unit	CONVENTIONAL SPRINKLER		MOBILE TRICKLE					
				10% Reduction		25% Reduction		50% Reduction	
		Year 1	Year 20	Year 1	Year 20	Year 1	Year 20	Year 1	Year 20
Crops									
Dryland Sorghum	acres	26.67	26.67	26.67	26.67	26.67	26.67	26.67	26.67
Irrigated Sorghum	acres	109.37	58.77	121.53	70.95	133.33	95.03	133.33	133.33
Irrigated Wheat	acres	23.96	74.56	11.80	62.38		38.30		
Saturated thickness	feet	145.29	58.07	145.70	66.21	146.38	78.57	147.59	101.69
Water level decline	feet	4.71	4.47	4.30	4.08	3.62	3.48	2.41	2.41
Returns to water and distribution system[b]	dollars	13256.76	7027.54	16216.78	9919.47	17873.18	13108.01	18364.17	18210.10
Present value of water and distribution system[b]	dollars	N.A.	195946.56	N.A.	245257.31	N.A.	294824.88	N.A.	330865.78

[a] Based on a 160 acre land unit with initial saturated thickness of 150 feet.

[b] Annual returns to land and management of $2738.06 or a present value over the 20 years of $30257.47 have been deleted. Fixed cost or investment for each distribution system has not been deleted.

attractive alternative, with limits on water availability in the summer months responsible for the shift of some acreage to irrigated wheat, which is irrigated in the fall and spring. The 26.67 acres of dryland sorghum associated with each alternative represents corners of the field which cannot be reached by a center pivot system.

As the aquifer is drawn down and well yield decreases, more acreage is diverted to wheat. Under the conventional system and the trickle system with 10 percent savings, wheat was included in the farm plan in the first year (23.96 and 11.8 acres, respectively). The trickle system with 25 and 50 percent improved efficiency planted all acres to grain sorghum in the first year. The annual rate of use for a 50 percent increase in water efficiency was reduced sufficiently so that the cropping pattern did not change over the 20 year planning horizon. Wheat acreage in year 20 was 74.56 for the conventional system, and 62.38 and 38.3 for the trickle systems with 10 and 25 percent improved efficiency, respectively.

Although the mobile trickle system produced more acres of the relatively more water intensive grain sorghum, the lower rates resulted in less annual water use, hence, less impact on the aquifer. Year 1 rate of decline in the static water level was 4.71 feet for a sprinkler compared to 4.3, 3.62 and 2.41 feet for the mobile trickle with 10, 25 and 50 percent improved water efficiency, respectively. Saturated thickness remaining after 20 years was 58.07 feet with a center pivot system compared to 66.21, 78.57 and 101.69 feet with the 10, 25 and 50 percent improved water efficiency systems, respectively.

The conventional sprinkler and the trickle system with 10 percent improved efficiency both show net returns in year 20 to be approximately $6,000 less than in year 1. However year 1 net returns are about three thousand dollars higher with the 10 percent improved efficiency. Benefits of the trickle system are more evident in examining the 25 and 50 percent more efficient systems, which show year 20 net returns decreased from year 1 by $4765.17 and $154.07, respectively.

The present value of the stream of income for the alternative systems provides an indication of increased returns to water and value to society for the 160 acre land unit. A 10 percent improved water efficiency with mobile trickle increases value of the water supply $49,310.75 and in addition results in over eight more feet of saturated thickness, after 20 years, compared to conventional sprinkler. The 25 and 50 percent improved water efficiency systems have an associated increase in present value of the water supply of $98,878.32 and $134,919.22 compared to sprinklers.

This indicates that, considering only the 1.74 million acres sprinkler irrigated on the Texas High Plains (New), the potential increase in returns to water over a 20 year period are $536 million, $1,075 million and $1,467 million for the 10, 25 and 50 percent water efficiency improvement. Of course, throughout the West and Great Plains the total would be increased several fold. Another interpretation would be that the increase in value of the water supply is an upper estimate of what society could afford on research to develop these new improved irrigation distribution systems.

New Crop Production Systems

Texas, for the most part, is a state where the price of natural gas is not regulated. In the period of 1973-75, in many regions, the price of natural gas increased over 450 percent. A second major disruption in many cotton producing regions was development of resistance to insecticide by the tobacco budworm. This, in conjunction with the rapidly rising cost of insecticides, created a difficult situation for producing cotton with traditional cotton production systems.

Through close cooperation and coordination of soil scientists, entomologists, agricultural engineers, and plant breeders a new production system was developed. The new system was based on a completely different variety, i.e., a short-season determinant cotton plant as compared to traditional long-season indeterminant varieties.

However, for the complete system to function as required, to get natural tobacco budworm control and fall diapause control of the boll weevil, involved careful management of fertilizer, irrigation and chemical insect control. Research results in Frio County for the new system indicated reduced energy use from 3.6 million kcal to 2.4 million kcal (33 percent savings), insecticide use reduced from 8 to 3 pounds of active ingredient and increase in farmer profit from $12 to between $95 and $160 per acre. Costs of production were reduced from 48 cents per pound of lint to between 27 and 34 cents (Sprott, et.al.). Table 15 provides an explicit comparison of the new system and the conventional system relative to level of inputs, production and economics.

The new crop production systems using short-season varieties are applicable to South Texas and the Coastal Bend regions. Cotton acreage in the Coastal Bend had declined from 190,000 in 1972 to 55,000 in 1975. It was projected in early 1976 that if the new cotton production

Table 15. A Per Acre Comparison of Cotton Production with Alternative Cotton Pest Management Practices: Frio County, Texas

		PRODUCTION TECHNIQUE			
ITEM	Unit	Typical[a]	Cooperating Producer	Short Season (40")	Short Season (26")
INPUTS					
Fertilizer	lb.	80-40-0	116-62-0	24-24-24	24-24-24
Irrigation	ac. in.	20	18	12	12
Pesticides	lb.	9.6	16.9	6.6	6.6
Total	1000 kcal.	3,624	3,645	2,445	2,445
Cost	$/ac.	278	326	281	279
Cost	¢/lb.	47.60	42.56	33.84	26.90
PRODUCTION					
Yield	lb./ac.	500	625	649	765
Gross[b]	$/ac.	340	435	452	532
Net[b]	$/ac.	62	109	170	252

[a] Based on enterprise budget published by the Texas Agricultural Extension Service.

[b] Based on a cotton price of $0.60/lb. for lint and $120/ton for seed.

Source: Sprott, J. Michael, et.al., "Agronomic, Economic, Energy and Environmental Implications of Short-Season Narrow-Row Cotton Production," Texas Agricultural Experiment Station MP-1250, February 1976.

systems were adopted in the Coastal Bend on the 55,000 acres of cotton plus 70,000 more acres were shifted from sorghum to the new cotton production system, regional benefits would be over $19 million. In 1977, there was 170,000 acres of cotton in the Coastal Bend with essentially all of it produced using the new cotton production system.

A similar cotton production system was initiated in the Trans Pecos region in demonstrations on farmer's land based on research results from Pecos and other regions of the state. The strategy involved short-season cotton varieties, reduced levels of fertilizer and irrigation and careful management. The 1975 demonstrations, with a very low level of inputs which included no insecticides, had a reduced lint yield from 700 pounds per acre with the conventional production system to 489 pounds. However, there as a dramatic reduction in production costs with the new strategy, from $546 per acre to $264. This amounts to reducing costs of production from 70 cents per pound of lint to 46 cents. More important, farmer profit was increased from a negative $68 per acre to a positive $63 per acre (Condra, Lindsey and Neeb). Table 16 provides a comparison of inputs, production and economics for the new and conventional systems.

With one year's experience, in 1976 the new program in the Trans Pecos on the average had a per acre lint yield of 575 pounds compared to 568 pounds for the conventional system. Again no insecticides were applied to the new cotton production system while 12 applications were applied through the conventional production strategy. Per acre costs of production were $302 for the new system and $445 for the conventional. Farmer profit for the new system was $161 per acre compared to $33 using

Table 16. Implications of an Improved Cotton Production System: Trans Pecos Region of Texas: 1975.

ITEM	UNIT	TRADITIONAL[a]	IMPROVED[b]	CHANGE
Yield	lb.	700	489	-211
Nitrogen	lb.	250	0	-250
Insecticide	appl.	7	[c]	- 7
Irrigation	ac.in.	44	21	- 23
Costs @ Acre				
Variable	dol.	460	206	-254
Total	dol.	546	264	-282
Costs @ Lb.				
Variable	dol.	0.66	0.42	-.24
Total	dol.	0.70	0.46	-.24

[a] Based on Texas Agricultural Extension Service published enterprise budgets.

[b] Based on 1975 test involving short season varieties.

[c] No insecticide applied, a scouting cost of $2.50 per acre was incurred.

Source: Condra, Gary D., Kenneth E. Lindsey and Charles W. Neeb, "A Proposal for an Upland Cotton Demonstration in Reeves and Pecos Counties," Texas Agricultural Extension Service, Fort Stockton, Texas, 1975.

the conventional system (Neeb, Lindsey and Condra). See Table 17 for details.

Indications are that we have reached the end of the era of inexpensive energy and the potential of insect resistance to insecticides significantly affects how irrigated crops will be produced. Further, the potential of pesticide bans by the Environmental Protection Agency can be expected to reduce the arsenal of chemicals available as well as seriously reduce incentive to develop new chemicals.

Thus, situations analogous to the traumatic conditions faced by Texas farmers can be expected to occur in other regions. The development of and adoption by producers of new crop production systems is dramatic and most encouraging.

The new low input-high management crop production systems are complex. Their development requires a close integration of several disciplines simultaneously. The effects of each are interrelated with each affecting other parts of the system. These interrelated impacts must be considered. The potential based on results of Texas work is phenomenal.

Although this discussion addressed new crop production systems for cotton, the next step is working with two or more crops in a single production system. This offers an even greater potential from new crop production systems. There are opportunities for improved biological control of insect pests, improved weed control, more efficient use of irrigation water and spreading of farmer's risk.

Table 17. Lint Yields and Profits Produced by the Texas Econocot System of Cotton Production Compared with Conventional Systems, Pecos Valley, 1976.

VARIETY	LINT YIELD LBS/AC	WATER AC/IN.	INSECT. APPL./ ACRE	COST/ ACRE	COST/ ACRE	NET RETURNS/ ACRE
Projected Results						
Typ. Prod. System	700	48	10	575	.74	6
Econocot Plan	630	30	3	377	.52	147
Achieved Results - Econocot System						
Location 1: Tamcot	848	15	0	331	.31	364
McNair 612	574	15	0	302	.45	134
Stoneville 213	582	15	0	302	.44	134
Deltapine 16	489	15	0	293	.52	108
NMSU 8890	384	15	0	281	.47	161
Average	575	15	0	302	.44	180
Achieved Results - Conventional System						
McNair 612	576	41	10	417	.64	67
Tamcot SP-21	559	48	13	472	.76	-2
Average	568	45	12	445	.70	33

Data collected by Charles Neeb, Ken Lindsey and Gary Condra, Texas Agricultural Extension Service, Texas A&M University.

Conclusions

This study is a summarization of many analyses and applications of different models. Each analysis was based on a given set of assumptions and subject to the limitations of the specific model and data. Thus, these results are subject to the limitations of each analysis which are enumerated in the detailed publication.

The expected impact of rising natural gas prices is a reduction in irrigation levels, farmer profit and present value of the groundwater supply. Indications are that natural gas prices will continue to rise and maintain economic pressure on irrigation farmers. Irrigation farmers in Texas are energy intensive with relatively high costs of production. Thus, price rises for an input such as natural gas where large quantities are used by each Texas irrigation producer impacts more severely than in other regions.

For the Texas High Plains, increasing natural gas prices could reduce the value of groundwater by 50 percent. In the Trans Pecos, with the assumption that energy prices would rise faster than crop prices, the average economic life expectancy of a typical farm is about five years. The probability of survival for 10 years is between 10 and 30 percent.

However, it can be concluded that the land purchaser at Trans Pecos has a higher life expectancy (5 yrs. vs. 8 yrs.) than the owner-renter or the renter. He also has a higher probability of survival (65% versus 20-25%) than the other tenure situations. His rate of return will be increased from -25.4% for the renter and -12.0% for the owner-renter to +8.7%.

The implications on farmer profit of rising natural gas price are dramatic. This study simply emphasizes the serious need to become more efficient in use of irrigation water and production of agricultural crops. There are many ways irrigated agriculture can respond to increasing energy prices. In Texas average pump efficiency was found to be about 52 percent, while natural gas efficiency averaged about 19 percent for 1968 (Ulich). Improving pump and engine efficiencies could result in a 41 percent reduction in energy used for irrigation in Texas (LePori and Lacewell). Similarly, Fischbach indicates that an annual savings of $3.1 million would result by improving pumping plant efficiency in Nebraska.

Continuing with the efficiency opportunities, increased use of tailwater recovery pits or re-use systems is needed. Fischbach indicates that in Nebraska re-use systems could save farmers $2.6 million per year in energy costs.

Essentially some long term solutions for irrigated agriculture lie in improved distribution systems and in reevaluating our crop production systems and developing new approaches. The improved distribution systems termed mobile trickle could offset significant energy price increases and enhance farmer profit; i.e., help in maintaining the value of the groundwater.

Regarding new crop production systems, the two new cotton production systems discussed have large reductions in inputs including irrigation. water. This is a significant improvement in view of rising energy prices.

In conclusion, with the expected continuation of rising energy prices, there is an especially urgent need to progress rapidly in development of new technology. The costs from not committing resources to this important and critical need are reduced agricultural output with corresponding rising prices, a serious cost-price squeeze for most irrigation farmers and severe implications for individual farmers as well as the rural communities.

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