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Impact of Alternative Energy Prices, Tenure Arrangements and Irrigation Technologies on a Typical Texas High Plains Farm

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IMPACT OF ALTERNATIVE ENERGY PRICES, TENURE ARRANGEMENTS AND IRRIGATION TECHNOLOGIES ON A TYPICAL TEXAS HIGH PLAINS FARM

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ABSTRACT

Irrigation is a major contributing factor in crop production on the Texas High Plains. It is responsible for greatly increasing crop production and farm income for the region. Two factors, a declining groundwater supply and increasing production costs, are of primary concern because they impact on farm operations and producer economic viability.

A recursive linear programming model for a typical Texas High Plains irrigated farm was developed to evaluate expected impact of price changes, tenure and new technology. The model includes a Fortran sub-routine that adjusts irrigation factors each year based on the linear programming solution of the previous year. After calculating new pumping energy requirements, well yield, and pumping lift, the Fortran component updates the linear programming model. This procedure continues automatically to the end of a specified planning period or to economic exhaustion of the groundwater, whichever occurs first.

Static applications of the model, in a deep water situation, showed that a natural gas price increase from $1.50 to $2.20 per thousand cubic feet (mcf) would result in reductions in irrigationlevels. Irrigation was terminated when the price of natural gas reached about $7.00 per mcf.

In a shallow water situation, much higher natural gas prices were reached ($3.60 per mcf) before short-run adjustments in farm organization began to occur. Under furrow irrigation, irrigation was terminated when the natural gas price reached $7.00 per mcf.

Increased natural gas prices impact heavily on returns above variable costs (up to 15 percent reductions) for a 60 percent natural gas price increase. The effects of rising natural gas prices over a longer period of time were more significant. Annual returns (above variable and fixed costs) were reduced by as much as 30 percent, and the present value of returns to water was reduced by as much as 80 percent as the natural gas price was increased annually by $0.25 per mcf (from $1.50 per mcf). The economic life of deep groundwater was shortened by as much as 18 years.

Renter-operators are even more vulnerable to rising natural gas prices than are owner-operators. With rising natural gas prices, profitability over time for the renter is low. As natural gas prices continue to increase, the greater will be the incentives for renter-operators to seek more favorable rental terms such as a sharing of irrigation costs.

With the problem of a declining groundwater supply and rising natural gas prices, an economic incentive exists for producers to find new technologies that will enable them to

make more efficient use of remaining groundwater and of natural gas. Substantial economic gains appear feasible through improved pump efficiency. Increasing pump efficiency from 50 to 75 percent will not increase the economic life of the water supply, but can improve farm profits over time; e.g., the present value of groundwater was increased 33 percent for a typical farm with an aquifer containing 250 feet of saturated thickness and 15 percent for 75 feet of saturated thickness.

Improved irrigation distribution systems can help conserve water and reduce irrigation costs. Results indicate that irrigation can be extended by 11 or more years with 50 percent improved distribution efficiency. In addition, the increase in present value of groundwater on the 1.69 million irrigated acres of the Texas High Plains was estimated to be $995 million with 50 percent improved efficiency.

Limitations in borrowing can substantially reduce annual net returns. This analysis suggests that the farmer can economically justify very high costs of borrowing rather than a limitation of funds available for operating expenses.

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CHAPTER 1

INTRODUCTION

Statement of the Problem

Agricultural production in recent years has experienced rapid increases in prices of inputs and higher variability of product prices. Although all of agriculture has essentially been exposed to the same input and product market factors, the implications are much more serious for high cost of production areas. Irrigated production in semi-arid and arid regions is typically energy intensive and characterized by high cost of production, particularly in states where natural gas prices are not regulated (Lacewell 1976, Condra and Lacewell 1976).

The Texas High Plains represents a semi-arid region where irrigation is an important factor of production. The importance of irrigation is reflected in its contribution to crop yields. Irrigation increases cotton yields approximately twice that of non-irrigated cotton and increases grain sorghum yields approximately six times that of dryland (Grubb and Lacewell 1970). Corn and soybeans, which account for over 31 percent of the irrigated acres, are produced only with irrigation (New

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The citations on the following pages follow the style of the American Journal of Agricultural Economics.

1976). In addition, irrigation removes much of the annual variation in output (Lacewell 1976).

However, the Texas High Plains has been experiencing a steady decline in groundwater. This decline in groundwater causes a lowering of the static water level, thus requiring increased amounts of energy for pumping. The resulting increase in the total cost of production is of utmost importance because it renders irrigated agriculture more vulnerable to energy price increases than non-irrigated agriculture (Lacewell 1976).

The combination of declining groundwater, increasing fuel requirements, and escalating prices of irrigation fuel leads to a rapid rise in production costs. Dramatic increases in the costs of production can result in a shortening of the "economic life of the water supply." The economic life of the water supply is the period of time over which returns attributable to water are positive. Conversely, economic exhaustion of the water supply is defined as that point when returns to water have declined to zero. With economic exhaustion of the water supply, irrigated production can be expected to revert to dryland crop production, pasture or to remain as idle acres.

Agricultural productive systems have been developed based upon abundant and cheap energy supplies and are energy intensive. Irrigated agriculture is especially so. In 1972, it was reported that about seven percent of energy used in Texas was in the agricultural sector (production, processing, and transportation). Thirty-nine percent of the energy used in agriculture was used to pump irrigation water, and 76 percent of this irrigation energy was provided by natural gas (Coble and LePori 1974).

The central problem faced by managers of irrigated farms is that rising natural gas prices and a declining irrigation water supply cause pumping costs to increase and thus impacts negatively on the farm's profitability. The farmer who irrigates needs to consider possible adjustments in farm plans that would potentially reduce requirements for both natural gas and irrigation water. Such adjustments could contribute to profitability of the irrigated farm and extend the economic life of the water supply. Adjustments might take the form of new technology which require less inputs (particularly less water and natural gas) or improved efficiencies from the pumping and distribution of irrigation water. Improved farm planning is needed to make more effective use of the limited irrigation water supply, irrigation fuel, and other scarce resources available to the farmer.

Objectives

The general objective of this study is to identify farm plans for a typical farm on the Texas High Plains that maximize the net present value of a limited groundwater supply. Specific objectives of the study are:

1. Develop a generalized recursive linear programming model for a typical farm on the Texas High Plains.
2. Estimate the temporal effects of rising energy prices upon a) cropping patterns, b) returns to the farmer, and c) net returns to water, for both sprinkler and furrow distribution systems.
3. Estimate the effects of different efficiencies of irrigation pumps on present value of the water supply.
4. Estimate the effects of alternative levels of efficiency for irrigation distribution on the years of pumping and present value of the water supply.
5. Estimate the effect(s) of credit constraints on typical farm situations.
6. Evaluate the effect of different farmland rental arrangements on producer net returns.

Description of the Study Area

The High Plains of Texas occupies about 35,000 square miles and includes 42 counties. The region is roughly rectangular, averaging about 300 miles north to south and 120 miles east to west. The Canadian River flows from west to east, dividing the region. When sufficient water is available, the area is well suited to agriculture (Texas Water Development Board 1977). Irrigation in the area is extensive. In 1948, irrigation wells numbered about 10,000, increasing by 1977 to 71,417 (New 1977). Irrigated acres in the Southern High Plains increased from 460,804 in 1949 to 4,593,178 in 1977.

In the Northern High Plains, irrigation development has been more recent. Irrigated acres increased from 12,591 in 1949 to 1,438,600 in 1977. In 1977, there was a total of 12,272,126 acres in cultivation on the Texas High Plains. Of this acreage, 4,660,068 were dryland, while 6,031,778 were irrigated (down 302,000 from 1976) and 1,580,250 remained idle (New 1976, 1977). Surface irrigation methods, primarily the furrow method, were used to water 78 percent of the irrigated acres, while sprinkler systems were used to irrigate 22 percent of the irrigated acres. In 1977, center-pivot sprinklers numbered 3,645 which was 35 percent of the total sprinkler systems (10,511). The number was an increase of 12 percent from the previous year.

The study area lies within a 21-county sub-region of the Texas High Plains, Figure 1. In 1977, 4.16 million acres in the study area were irrigated (New 1977). This was approximately 69 percent of that for the entire High Plains of Texas (6.03 million acres). Irrigation wells in the study area numbered 37,010, just over half of the total irrigation wells on the Texas High Plains (71,417).

The area is characterized by medium to fine-textured soils, including Pullman, Lofton, and Olton clay loams and Amarillo and Mansaker loams (Texas Department of Agriculture and Soil Conservation Service 1978). These soils are capable of high yields, but their productivity is limited by the area's climate, in particular, low rainfall and a short growing season. The growing season for the region averages from 178 to 214 days. The minimum average temperature in January ranges from 19 to 26 degrees, while the maximum average July temperature is from 92 to 95 degrees.

Average annual rainfall ranges from a low of 17.38 inches in Dallam County to a high of 22.16 inches in Hansford County. Amarillo, central to the area, receives an average of 20.43 inches. Records for Amarillo show a high degree of variability in rainfall with an annual low of 9.56 inches and a high of 37.21 inches from 1938 through 1977 (U. S. Department of Commerce 1977). Most of the area's rainfall (about 75 percent) occurs during the growing season (April through September).

A low relative humidity and a high evaporation rate are characteristic of the region. "Lake Evaporation"[1] is about 68 percent of the annual rainfall (U. S. Department of Commerce 1977). While evaporation from the soil

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[1] Lake evaporation is the amount of evaporation that would occur from an exposed body of water.

is less than the lake evaporation rate, it is quite significant, and the efficiency of irrigation is thereby affected.

The principal crops are corn, grain sorghum, and wheat to the north of the Canadian River, while to the south of the Canadian River cotton is grown in addition to the above crops. Soybeans are also produced in the study region primarily as a "catch crop."[2] Wheat is typically grazed by stocker cattle and then harvested for grain. All of the above crops are produced under irrigation, while cotton, grain sorghum, and wheat can also be produced dryland.

Water Supply

Groundwater used for irrigation lies within the Ogallala aquifer. The Ogallala geological formation occurs at or near the surface over much of a 42-county area of northwest Texas. The geological formation consists of alternating beds of silt, clay, gravel, and caliche. In the irrigation area to the north and west of Lubbock, saturated thickness ranges from 100 to 300 feet. To the north of Amarillo, saturated thickness varies to more than 500 feet (Texas Water Development

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[2] A catch crop is a replacement crop for one that has been severely damaged or destroyed.

Board 1977). The "coefficient of storage"[3] for the aquifer has been estimated to be about 15 percent (Cronin 1961).

The water supply held in the Ogallala aquifer is deing depleted by irrigation. Depletion of the water supply will continue as long as the rate of extraction exceeds the recharge rate. The average annual water-level decline from 1960 to 1972 is estimated to range from .5 foot to 3.9 foot, depending partly upon the original saturated thickness of the Ogallala water formation (Wyatt, Bell, and Morrison 1978). The annual rate of water pumped in 1970 is estimated to have been 5,128,818 acre feet. The rate of pumping is expected to peak at 6,003,560 acre feet in 1990 as shown in Table 1. Natural recharge per annum of the water supply has been estimated to be .8 of an inch or less. However, due to changes in the soil and land surfaces that have accompanied large-scale irrigation projects, there is some evidence that recharge is more than these earlier estimates indicated (Wyatt, Bell, and Morrison 1978). This recharge is from surface water only (precipitation and irrigation). With this slight recharge and heavy use

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[3] The coefficient of storage is a measure of the water storage capacity of an aquifer. It is defined as "the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of the head normal to that surface" (Texas Water Development Board 1977).

Table 1. Estimates of Historical and Future Pumpage from the Ogallala Aquifer for a 45-County Region of the Texas High Plains.[a]

Year	Estimates of water pumped	Annual Pumping Rate[b]
	(ac ft)	(%)
1970	5,128,818	1.4
1980	5,485,990	1.5
1990	6,033,560	1.7
2000	5,506,675	1.5
2010	4,848,457	1.4
2020	4,397,555	1.2

Source: Wyatt 1975

[a] The estimates include factors for natural recharge and irrigation recirculation. Wyatt included 45 counties in his study while some other studies included only 42 counties.

[b] Annual pumping rate is shown as a percent of the estimated 1970 underground water supply.

for irrigation, water depletion appears inevitable, at least to the point that it is no longer economically feasible to use the water for irrigation purposes.

Wyatt (1975) reports on a study of a 45-county region of the Texas High Plains (as compared to 42 counties in studies previously cited) in which estimates were made of recoverable volumes of water in storage along with projections of recoverable volumes for the years of 1970 to 2020, as shown in Table 2 (Wyatt 1975). These depletion projections were based upon water usage which occured between 1960 and 1972. The projected recoverable volume of water in the year 2020 (126,989,000 acre feet) is 35.6 percent of the estimated 1970 volume (356,331,000 acre feet). While the projected volume for year 2020 might seem to be a large quantity remaining, recovery of the water will be at higher costs (Lacewell, Jones, and Osborn 1976).

There are many unpredictable factors which can influence the future use of groundwater from the Ogallala formation. Among these factors are the following:

"1. the amounts and distribution of precipitation which will be received in the area in the future,

2. Federal crop acreage controls or the lack thereof,

3. the price and demand for food and fiber grown in that area,

4. the cost of energy to produce water,

5. availability and cost of farm labor, and

Table 2. Estimates of Recoverable Volumes of Water from the Ogallala Aquifer in Acre Feet from 1970 to 2020, for a 45-County Region of the Texas High Plains.

Year	Estimates of recoverable volume of water in storage	Remaining volume as a percent of the 1970 estimate
	(ac ft)	(%)
1970	356,331,000	100.0
1974	340,082,000	95.4
1976	324,393,000[a]	91.0
1980	293,016,000	82.2
1990	242,457,000	68.0
2000	197,512,000	55.4
2010	159,047,000	44.6
2020	126,989,000	35.6

Source: Wyatt 1975

[a] Derived from interpolation

6. soil and water conservation measures employed by the High Plains irrigator" (Wyatt, Bell, and Morrison 1978).

Irrigation Fuel

Natural gas is the principal fuel used for irrigation in the Texas High Plains. In 1976, 64 percent of the irrigation units were powered by natural gas, and 34 percent used electricity. Only 2 percent operated on liquid petroleum, and only 209 units used diesel or gasoline (New 1976).

The price of natural gas paid by farmers of the study area has been increasing rapidly. In 1970, producers were paying \$0.30 per thousand cubic feet (mcf) (Shipley 1977b). As of February, 1979, the average price of natural gas for irrigation had risen to about \$1.69 per mcf (Carthel 1979). The price of natural gas varies, depending upon the level of use. Rates currently charged by Pioneer Natural Gas Company for irrigation in early 1979 are shown in Table 28, Appendix A. The rates include an average "fuel adjustment cost" of \$0.5864 per mcf. Pioneer Natural Gas Company is permitted to increase their rates as the cost rises for natural gas they purchase. Hence, their increased costs of acquiring natural gas supplies are passed on to the irrigation farmers in the form of a fuel adjustment cost. It is estimated that the rates will increase approximately 1½ to 2 cents per mcf per month due to the fuel adjustment cost (Carthel 1979).

Estimates of the average price of electricity for irrigation in July, 1978, ranged from 3.2 cents per kilowatt hour (kwh) (Glover 1978) to 3.9 cents per kwh (Reynolds 1978). As of February, 1979, prices had increased to near 4.9 cents per kwh in some regions on the Texas High Plains, an increase of at least 26 percent in seven months (Davis 1979, Reynolds 1979). Additional increases can be expected as a result of the fuel adjustment cost.

An Overview of the Study

In the following section, past studies are reviewed and highlighted which bear upon irrigated farming in the Texas High Plains. These studies provide insight regarding effects upon irrigated farm operations where there is a declining groundwater supply and increasing prices for natural gas used for irrigation fuel. In addition, possible strategies for farmers to conserve or make more efficient use of the declining irrigation water supply are discussed.

Economic theory is presented for allocating a firm's scarce resources among competing uses so as to maximize net returns to the farm firm. In particular, production economic theory is used to explain the demand for a purchased input and also to explain resource and production adjustments in response to changing prices of those resources and products.

The development of a recursive linear-programming model is discussed. This model provides the analytical tool for evaluating a number of issues. The results apply to a typical irrigated farm under alternative water resource situations. The analysis emphasizes effects of fuel price, technology, financial constraints, and tenure. Adjustments are presented in terms of cropping pattern changes, years of irrigation, and present value of the specified water situation.

CHAPTER II

LITERATURE REVIEW

This study involves Texas High Plains irrigation and the effects of a declining aquifer, price changes, new technology, and tenure. The analysis is based on application of a linear programming (LP) model. Therefore, the literature review initially discusses a variety of studies that make various uses of linear programming. The discussion then is directed to extensions of LP as well as other quantitative techniques and implications of other studies.

Irrigation Water Demand

Linear programming techniques have been employed extensively for demand analysis, including demand for irrigation water. Moore and Hedges (1963) applied linear programming with a profit maximizing criteria to estimate derived demand for irrigation water in Tulare County, California. They first used parametric programming to obtain estimates of derived demand for representative farms of five different sizes. The representative farm demand schedules were then aggregated by means of weights based on the distribution of farm sizes in the study area. The aggregate price elasticity of demand was inelastic to a price of about $16.50 per acre foot. At that price there occurred a dramatic decline in the quantity of water demanded.

Shumway (1973) developed a regional linear programming (LP) allocation model for California to derive demand for irrigation water as a productive input to agriculture for the west side of the San Joaquin Valley. The LP model contained a cost of production objective function and sought least-cost production of a target output for the region. Parametric techniques were used to estimate derived demand for irrigation water directly for the region. It was estimated that demand for water was elastic above and inelastic below a price of $8.50 per acre foot. At that price, total revenues from water sales by the state would have been maximized. When variable costs are taken into account, the price at which net returns on the state's investment are maximized would be higher than that at which total revenue is maximized. At a price of $13.00 per acre foot, net returns on the state's investment (in the water project) would have been maximized.

In 1971, Harman, Hughes, and Martin, by means of linear programming, estimated long-run demand for irrigation water for an individual producer on the Texas High Plains. The analysis assessed the prospects of maintaining annual incomes of $5,000, $7,000, and $10,000, with a land charge of $22.50 per acre. Barring an improvement in technology, a commodity price increase, or a production cost decrease that would result in higher farm income, a water cost in excess of $15 per acre could be sustained only at the expense of family living standards or current land values.

Lacewell and Condra (1976) conducted a regional study in which they evaluated the effects of changing input and product prices on the demand for irrigation water in Texas. They developed linear programming models for three regions in the Southern High Plains. Purchasing and selling activities allowed prices on inputs and crops to be adjusted parametrically. In addition, crop acreage flexibility coefficients were estimated from historically planted acreages. Based on variable production costs only, when the price of water increased to $71.25 per acre foot plus pumping costs, all production shifted to dryland (Condra, Lacewell, Sprott, and Adams 1975). When the analysis included variable and fixed costs, all land reverted to dryland production when the price of water increased to $24.47 plus current pumping cost. The shifts in cropping patterns occurred at much lower prices when fixed costs were included, which suggests that in the long-run, irrigation in the study area is very sensitive to the price of fuel used in pumping water.

Hartman and Whittelsey (1961) formulated a LP model for an irrigated farm firm in Colorado. They used the model to derive marginal values for irrigation water within irrigation periods.

Yaron (1967) also employed LP to analyze the demand for irrigation water. Instead of estimating the demand for irrigation water by using a parametric objective function, Yaron varied selected factors within the framework of LP models and analyzed their effects on the demand for water. As the factors were varied, the marginal value product (shadow price) of water was generated. The studies indicated that two of the most important factors which affect the demand for water are the particular irrigation techniques applied on the farms and the degree of farmer mobility.

Fuel Price Effects

Other studies have dealt more directly with the effects of increasing prices of irrigation fuel. Mapp and Dobbins (1976) developed a recursive linear programming model to evaluate effects of rising natural gas prices in the Oklahoma Panhandle. Optimum organizations were developed for representative farms in poor, moderate, and good water situations for (1) conventional tillage and (2) reduced and conventional tillage, with both low and high crop prices, under conditions of constant and rising natural gas prices. With reduced tillage there was an increase in water usage. Net returns were higher during early years with reduced tillage, but increased pumping costs of later years reduced net returns significantly.

Similarly, Young used linear programming in a temporal analysis for the Texas High Plains to evaluate the effects of rising natural gas prices (1977). As the price of natural gas increased from $1.25 per mcf to $3.00 per mcf, it was estimated that the regional impact would be a three percent decline in total irrigation acreage, a 15 to 20 percent decrease in net farm income, and a 15 to 16 percent decrease in productive value of land. All acreage reverted to dryland production for natural gas prices from $5.50 to $9.00 per mcf with a furrow distribution system and from $2.75 to $6.50 per mcf for a sprinkler system.

Adams, Lacewell, and Condra (1976) evaluated the effects of rising prices of energy and energy-related inputs in the Southern High Plains. Energy inputs considered were natural gas, diesel, and nitrogen fertilizer. The prices of certain commodities and the energy inputs were changed parametrically over a specified range. In the short-run (assuming average commodity prices) the study indicated that Texas High Plains farmers would continue to produce at current levels with established cropping patterns until diesel price increased to about $2.00 per gallon, natural gas to approximately $4.00 per mcf, or nitrogen price to near $0.40 per pound.

Temporal Resource Allocation

An issue of great concern to Texas High Plains farmers is the declining groundwater supply now used for irrigation. It becomes the farmer's task to allocate the limited water supply not only among competing crops but over the economic life of the water. Lacewell (1966) used linear programming to estimate a typical farm's water supply as a function of capital investment in wells and as a function of saturated thickness of the aquifer. He further determined farm plans that maximized the present value of the farm's water supply. From 42 farm programs included in the analysis, one optimum farm program was identified that resulted in the largest present value of the net farm income stream over the life of the remaining water supply.

Burt (1964, 1967) considered the problem of the temporal allocation of groundwater. An optimal policy for temporal allocation of water weighs the urgency of current production against (1) diminishing returns with respect to water used in a given period, (2) increasing pumping costs with depletion of supply, and (3) the insurance value of stocks against uncertainty. The decision rules for temporal allocation of groundwater were derived by Burt using dynamic programming.

Harman, Hughes, and Martin (1971) evaluated possible adjustments to a declining irrigation water supply. They found that a substantial increase in farm size will not necessarily offset the loss in individual farm income and land values which accompany a shift from irrigated to dryland production.

Still another study, by Lacewell and Pearce (1973), evaluated the declining groundwater in the Texas High Plains and costs of operating different distribution systems. Well yield and variable pumping costs were calculated over time with a declining static water level with a recursive simulated model. With low-yielding wells, the labor-intensive hand-moved irrigation distribution systems resulted in the highest net present value to the water supply. But with higher yielding wells, the advantage shifted toward more capital-intensive methods, the side-roll system and the center-pivot sprinkler system.

The regional problem of the declining groundwater in the Texas High Plains was considered by Lacewell, Jones, and Osborn (1977). They concluded that irrigation development in the High Plains is likely to continue to increase in ensuing years, with water pumpage and irrigated acres reaching a peak in 1990 and then declining. This was due to declining groundwater. Concurrent with the decline in irrigated areas would be (1) production shifting to more grain sorghum and (2) substantial reduction in agricultural output and farm income.

Hughes and Harman (1969) utilized a recursive LP model and 1966 prices to estimate that the annual gross value of agricultural output for the High Plains would change from $432 million in 1966 to $128 million by 2015, a 70 percent reduction. They also projected that aggregate net returns to farmers would, for the same period, decline 74 percent, from $194 million to $50.5 million.

Osborn and Harris (1973), using an input-output model, estimated benefits from irrigated agriculture accruing in agriculture and non-agriculture sectors for a 56-county area of Texas. Benefits were estimated for 1967 and projected for 2015. Estimated benefits for 1967 were $1.7 billion compared to $.8 billion in 2016, a decrease of 53 percent. Total household incomes, employment level, number of households, and population of the Amarillo area are expected to increase until about 1990 and then decline (Osborn, Harris and Owens 1974).

Casey (1977) developed a recursive LP/input-output model for a region of the High Plains of Texas and Oklahoma. The model allocated the region's limited water supply to maximize producer net returns subject to constraints in the LP segment of the model. The model was used to estimate regional effects of alternative rates of irrigation development in the High Plains. The results indicate that adequate groundwater is available for growth in agriculture output during the next few years. But, producers should not be optimistic about sustained growth in regional agriculture output beyond 1990.

Improved Efficiency and New Technology

Attention is being directed toward developing new production systems which reduce the production costs per unit of output. In Texas a new production system has been developed for cotton. This sytem, referred to as "econocot," involves detailed coordination of all inputs including seed variety, fertilizer, irrigation, row spacing, and pest control (Lacewell 1978). A short-season variety of cotton is grown in narrow rows with a reduced level of irrigation and fertilization. Results relative to yields and net returns have been mixed in different regions, but due to dramatic reductions in insecticide use and other inputs, production costs have generally decreased and net returns have increased. In 1976, field trials in the Trans-Pecos area of Texas showed a 34 percent reduction in variable costs and a 30 percent decrease in fixed costs (Lindsey, et al. 1976). The system does, however, require high level management, without which the system can produce unsatisfactory results.

Lacewell evaluated opportunities for developing new crop varieties that are resistant to weeds, disease, insects, and drought and that have desirable production characteristics (Lacewell 1978). He estimated annual economic benefits resulting from a past development of a variety of grain sorghum resistant to greenbugs. The variety resulted in reduced levels of insecticide use and prevented reduced yields. Annual benefits accruing to the Texas High Plains were estimated to exceed $60 million. Other such advances in technology can reap similar economic benefits. The development of drought resistant varieties can increase the efficiency of water use and extend the economic life of the water supply.

There are opportunities for the irrigation farmer to improve efficiencies of (1) irrigation wells, (2) pumping plants, and (3) irrigation distribution systems. Improved efficiencies will enable the irrigation farmer to better cope with a declining groundwater supply and increasing natural gas prices.

The yields of many existing High Plains irrigation wells are well below their potential due to inefficient well establishment and development. This reduces efficiency and increases cost per acre foot of water pumped. Lyle (1976) evaluated efficiencies from a properly designed and equipped irrigation well located at the High Plains Research Foundation, Halfway, Texas. The well yielded 1300 gpm, as compared with two nearby wells producing 350 and 400 gallons per minute (gpm) which indicated that many area wells could be pumping water more efficiently. While the drilling of such a well is expensive, it is possible to increase well yields without increasing fuel costs and to increase the effective pumping efficiency over the life of the pump.

The efficiency of the pumping plant is a vital concern because it affects the cost of pumping irrigation water. The more efficient the pumping plant, the less fuel required to pump a unit of water. The reduced fuel requirement results in a lower per unit cost of pumping water. Pumping plant efficiency is determined as the multiplicative of the efficiency of individual components (pump, drive, and power unit) (Ulich and Sechrist 1968). Electrically powered pumping plants are usually of much higher efficiency than pumping plants using internal combustion engines, as shown in Table 3. While the overall efficiency of internal combustion engines is inherently low, the cost of natural gas is also relatively low, and when comparisons are made between other power pumping units and internal combustion engine pumping units, the total costs should be used rather than fuel costs or simple efficiencies.

Ulich and Sechrist measured the efficiency of a number of different types of pumping plants. Electrical units with vertical hollow shafts had an average pumping plant efficiency of 48.6 percent, while electrical submersible units had an average efficiency of 35.6 percent.

Table 3. Average Irrigation Pumping Plant Efficiencies on the Texas High Plains.

Power Plant Components	Fuel Type		
	Natural Gas	Electric (type)	
		Vertical Hollowshaft	Submersible
	(%)	(%)	(%)
Motor or Engine	19.8	89.9	41.4
Gearhead	95.	-	-
Pump	56.7	54.	43.5
Overall Efficiency[a]	10.1	48.6	35.6

Source: Ulich and Sechrist 1968.

[a] The overall efficiency is the percent efficiency calculated from the amount of fuel or energy input to the unit and the amount of work performed by the pumping plant.

Units with internal combustion engines fueled with natural gas had efficiencies ranging from 2.1 to 20.0 percent, with an average of 10.1 percent. Since the majority of the power plants in the Texas High Plains are fueled with natural gas (64 percent in 1976) (New 1976), these low efficiencies and increasing prices for natural gas are causing pumping costs to become a more significant factor of production.

The development of more efficient distribution systems can reduce irrigation costs and conserve the remaining groundwater supply. Several systems are currently being used on a trial basis, such as a "trickle system" (Hiler 1975), a "drip system" (Shipley 1977), and a "low energy precision application system" (Lyle 1979). These systems operate with low water pressure and reduce the water lost to evaporation by delivering a greater proportion of water pumped to the root zone area. Shipley (1977) reported that irrigation of corn using a drip system reduced water used by 50 percent and doubled corn yields but tripled irrigation costs. Further research is needed on economic feasibility of such systems.

Finance

Declining groundwater supplies, rising input prices and increasing variability of product prices all reflect on cash flow and financial aspects of a farm operation.

With inflation and rising risk there is a need for a producer to maintain a reasonable level of liquidity. Reserved credit (unused capacity to borrow) is a valuable source of liquidity for the farmer. It exists when a farmer restricts his borrowing to some level below his maximum capacity to borrow. With credit reserves the farmer is better able to cope with uncertain expectations. Barry and Baker (1971) estimated values of reservation prices associated with firm liquidity provided by unused credit by use of a multi-period linear programming model. In the model the cost of borrowing was increased in the objective function until solutions approached growth rates that were empirically observed for two case farmers. Farmer One's average annual net worth growth rate was $9.45 per acre. This growth rate was associated with a credit reservation price of $0.25 to $0.30 per $1.00 of credit. Reservation prices in this range imply a relatively high degree of debt aversion.

Farmer Two's net worth grew at an average annual rate of $18.54 per acre. The reservation price associated with this growth rate was in the range of $0.01 to $0.03, which implies a relatively low degree of debt aversion.

Tenure

The viability and implication of rising energy prices affect renters differently than owner-operators. It is important to identify these impacts.

Benedictis and Timmons (1961) made use of linear programming to identify and measure inefficiencies of farmland leasing arrangements. The LP technique was used to determine optimum farm plans for intratemporal use of resources (static analysis) under owner-operatorship and alternative kinds of farm leases. Basic assumptions were made that both parties desire to maximize their net income from the use of a particular quantity of resources. As a norm, they used the optimum farm plan derived for an owner-operator situation. With this, they compared the landlord's and tenant's optimum farm plans.

Performing an analysis for the years 1951 to 1955, results indicated that neither the crop-share nor cash-lease arrangements met the efficiency conditions. For each year, aggregate landlord and tenant net returns were below net returns for the optimum owner-operator farm plan. The reductions in the aggregate net returns due to farm rental arrangements were attributed to the misallocation of resources at the firm level. Both the landlord's and the tenant's optimum farm plans leave part of the tenant's capital idle due to the limited capital contributed by the landlord. Benedictis and Timmons also suggested the LP techniques could be employed to study economic consequences of provisions of leases rooted in custom and tradition. Such inquiry could provide results of economic sacrifices associated with particular lease provisions. Thus, the landlords and tenants could consider altering customary lease arrangements in view of the associated consequences.

The above reports briefly discuss the most important of the past studies that are available and indicate the nature of past research as well as basic implications. Each of these studies provide both explicit and implicit input to the present work, providing a valuable framework.

CHAPTER III

ECONOMIC THEORY

The typical farm operator of the Texas High Plains is confronted with the task of allocating available resources so as to maximize net returns to the farm. The primary limiting resources of a farm operator in this area are (1) land, (2) irrigation water, (3) labor and (4) operating capital. The limiting supply of irrigation water is a major focus of this study. There is a limited quantity of water available within each year. In addition, the total water is exhaustible. Production economic theory is relevant to the efficient allocation of scarce resources in the production process. Thus, micro-economic theory or production economic principles underlie this study. This chapter describes some of the theoretical principles related to optimum temporal use of an exhaustible resource, implications of changes in technology, the role of finance, and the relationship between linear programming and marginal analysis.

Allocation of Variable Resources

Economic theory provides insight to a firm's demand for variable production resources. Assuming profit-maximizing behavior by the firm and perfect competition in the product market[4], the firm's demand for a single variable resource can be depicted by a marginal value product (MVP) curve of that resource as shown in Figure 2, graph a (Leftwich 1966). The MVP curve shows the quantity of the resource that the firm would employ at each price level. The firm seeking to maximize profits, would employ that quantity of the resource for which $MVP_x = P_x$.

On the other hand, when a firm employs several variable resources its demand curve for any of the resources can no longer be represented simply by a MVP curve. When several variable resources are used (with x_1 being one of the variable resources) a change in the price of x_1, assuming the prices of the other resources to remain constant, will result in changes in the quantities of the other resources demanded, and these changes will in turn affect the quantity of x_1 demanded. Internal adjustments are made by the firm to reestablish a least-cost combination of resources. The demand for the variable x_1 is illustrated in Figure 2, graph b. In this instance, the other resources are complementary to x_1. $MVP^0_{x_1}$ is shown as the initial MVP curve, and $P^0_{x_1}$ is the initial price for x_1. A decrease in the price of x_1 to $P^1_{x_1}$ will result in the firm increasing employment from x^0_1 to x^1_1. This increased employment of x_1 will cause the marginal

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[4] Given perfect competition in the product market, the marginal value product of resource x_1 is equal to the marginal physical product of x_1 times the price of the product (P_y), i.e., $MPP_{x_1} \cdot P_y$.

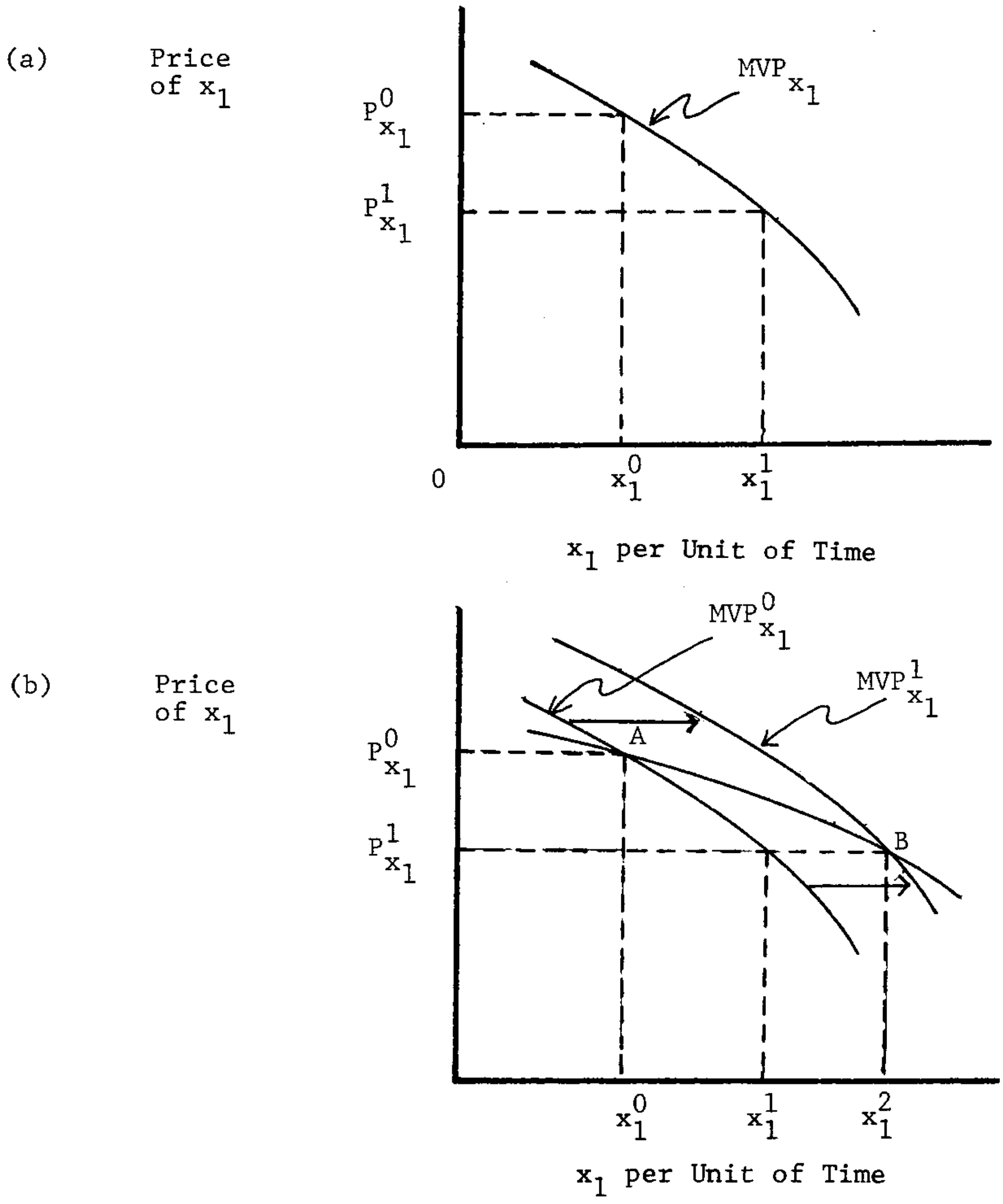

Figure 2. Demand for a variable resource, x_1, with: (a) other resources fixed and (b) other resources variable and complementary to x_1.

value of product (MVP) of complementary resources to shift to the right. The quantities demanded of the complementary resources will increase, which, in turn will shift the marginal physical product and the marginal value of product x_1 to the right as shown by MVP_x^1. The quantity of x_1 that will then be demanded by the firm at $P_{x_1}^1$ will increase to x_1^2. And the firm's demand curve for x_1 can be traced through points A and B. If the other resources had been substitute resources, their MVP curves would have shifted to the left, resulting in less of their use. At the same time, MVP_{x_1} would shift to the right, resulting in the use of more x_1. A principal point is that the prices and the quantities of the resources employed are interrelated, and a change in the price of a given resource can lead to internal adjustments involving other resources as well.

In the instance of two variable resources, expansion of output would occur along the expansion path, which shows the least-cost combinations of producing each level of output. Along the expansion path, the equality $MPP_{x_1}/P_{x_1} = MPP_{x_2}/P_{x_2}$ prevails. Output would be increased (as shown in Figure 3) from point 0 to point D, where

$$\frac{MVP_{x_1}}{P_{x_1}} = \frac{MVP_{x_2}}{P_{x_2}} = 1 \qquad (1)$$

Profits are maximized at point D. In the case of multiple inputs, profit would be maximized by that output where

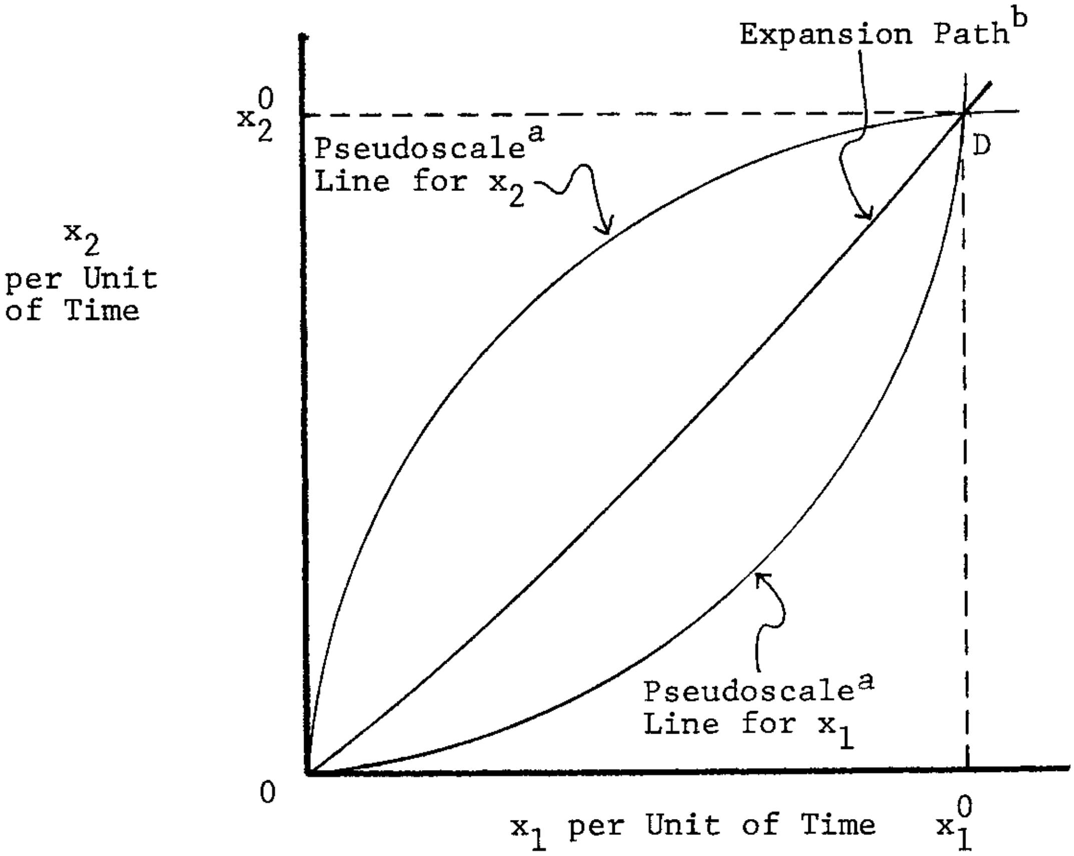

Figure 3. Factor-factor model with least-cost combinations and pseudoscale lines.

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[a] The pseudoscale line is a locus of points along which

$$\frac{MVP_{x_i}}{P_{x_i}} = 1$$

[b] The expansion path (least-cost combinations) is a locus of points along which

$$\frac{MPP_{x_1}}{P_{x_1}} = \frac{MPP_{x_2}}{P_{x_2}}$$

$$\frac{MVP_{x_i}}{P_{x_i}} = 1 \qquad (2)$$

where x_i = variable resource i. This equality for one resource is defined as the pseudoscale line and is illustrated for x_1 and x_2 in Figure 3.

Allocation of an Exhaustible Resource

Temporal Analysis

Irrigation water in the Texas High Plains exists in limited quantity (a fixed resource). Since the rate of replenishment is only a fraction of the rate of extraction, the water supply is an exhaustible one. "Exhaustible is a concept that is meaningful only when used in the economic sense" (Ciracy-Wantrup 1952). Long before a given resource is physically used up, it may be exhausted in the sense that further use is terminated in spite of human wants. This is true because, in any additional interval, the costs of producing any possible quantity of this resource (water) may be greater than the revenues derived from the use of this quantity. While economic exhaustion only is recognized in the preceding statements, there are some situations in which physical exhaustion of the water supply, for all practical purposes, can and sometimes does occur prior to economic exhaustion.

Allocation of the exhaustible water supply involves not only the distribution of water among competing crops within each year but also the allocation of water over time or among years. The optimum allocation of water over time (which maximizes profits) is stated as follows (Scott 1955, Lacewell 1966):

$$MNR_{x_1} = MUC_{x_1} \tag{3}$$

where

MNR_{x_1} = additional net revenues in the present time period from one unit of x_1, the exhaustible resource,

MUC_{x_1} = discounted additional net revenue in a future period from one more unit of the exhaustible resource.

It is noted that the model used in the study does not allocate water supply over time to maximize present value of returns to water because of research budget constraints. Therefore, the model used maximizes annual net returns, which is assumed to approximate the behavior of many area farmers.

Discounting Procedure

Discounting is a mathematical procedure used to determine the present value of future income streams over different time periods (Hopkin, Barry, and Baker 1973). It is a means of putting revenues received at different time periods on a comparable time basis. Interest rates are described as the exchange prices between present and future value of financial claims. The discount rate, mentioned above, is an individual's preference for money over time which is, in great part, subjective in nature. Higher levels of a discount rate reflect a stronger time preference for more current returns, i.e., a higher price must be paid for waiting for future revenues (Hopkin, Barry, and Baker 1973). A higher discount rate results in the more current revenues being of greater relative significance than more future revenues. This results in a faster rate of resource use, resulting in a faster rate of depletion.

The discount rate is far more than simply a market interest rate. The investor or manager might discount future revenues (1) by a rate which he considers to be an appropriate alternative earning rate (opportunity cost[5]) plus (2) a "subjective" amount of the uncertainty of future revenues (Heady 1952; Weston and Brigham 1978). Uncertainty relative to weather patterns (rainfall) which affect current economic viability results in farmers tending to irrigate more heavily in current years. Short-term tenancy can likewise bear heavily upon the farmer's expectation of future revenues. Revenues past the expected term of tenancy are understandably given little or no consideration. Depletion

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[5] Opportunity costs for a given product are the values of the foregone alternative products that the resources used could have produced (Leftwich 1973).

of irrigation water would tend to be accelerated in such a case. Long-term tenancy would encourage a decreased rate of depletion.

Additionally, a farmer might discount future returns very heavily (a high discount rate) due to current liquidity needs. A farmer might deplete irrigation water more rapidly because of needs to generate revenue with which to service debts or to meet increased family consumption needs (such as financing a son's or daughter's college education). Hence, liquidity needs are reflected in the discount rate and can influence the rate of water use.

Short-Run Allocation

The proper allocation of a variable resource and a fixed, exhaustible resource for a given year are illustrated in Figure 4, with x_2 as the variable resource and x_1 as the fixed, exhaustible resource (irrigation water supply). The quantity of water available for the year is x_1^0. Assuming a water user cost ($P_{x_1} > 0$), there is a pseudoscale line for water and an expansion path. Resource use would follow the expansion path out from the origin to the annual pumping capacity (from point 0 to point B) then up to the pseudoscale line for x_2 (from point B to point C). Point C indicates the profit maximizing quantity of the variable resource (x_2^0) that corresponds to the fixed quantity of water (x_1^0). Annual pumping (x_1^0) is affected by well capacity and critical water periods for plants within the production year.

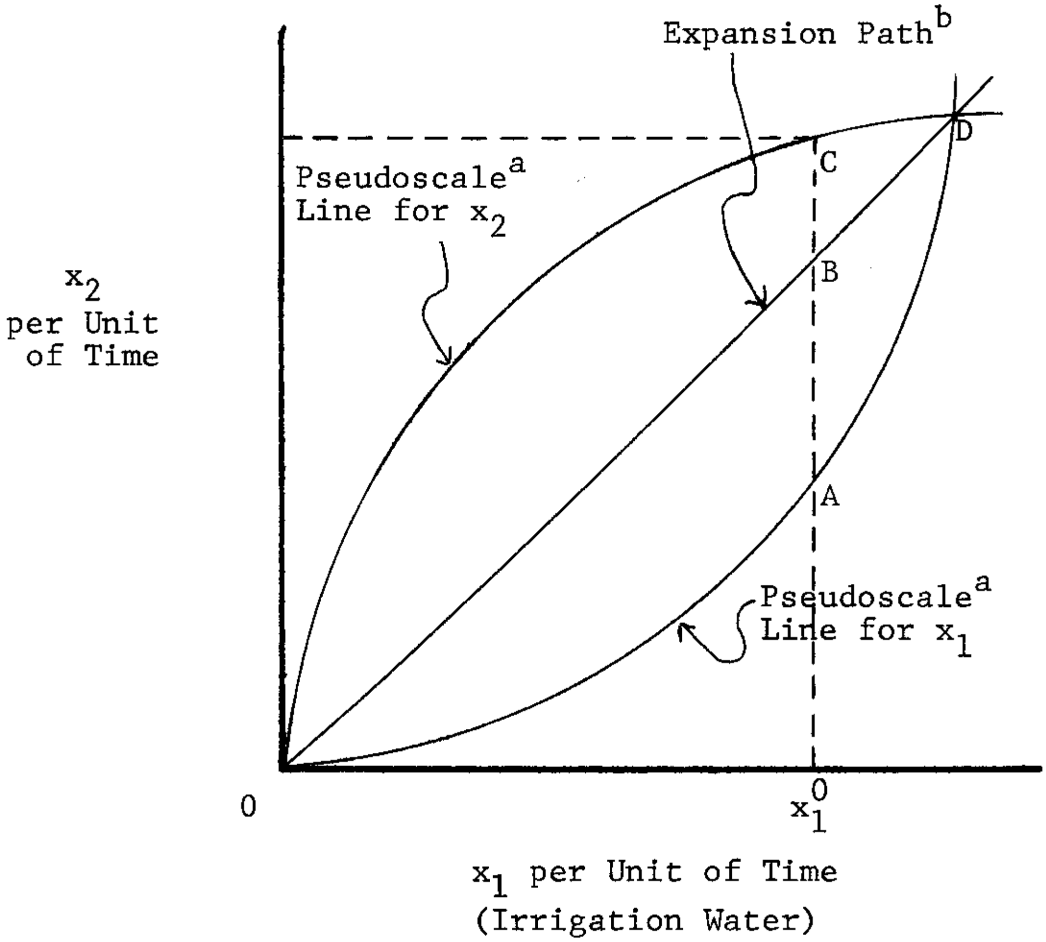

Figure 4. Factor-factor model and optimum resource allocation with irrigation water quantity fixed on an annual basis.

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[a] The pseudoscale line is a locus of points along which

$$\frac{MVP_{x_i}}{P_{x_i}} = 1$$

[b] The expansion path (least-cost combinations) is a locus of points along which $\frac{MPP_{x_1}}{P_{x_1}} = \frac{MPP_{x_2}}{P_{x_2}}$

As pumping continues, static water level and saturated thickness of the aquifer decline. This means well yields decline, as illustrated in Figure 5, and pumping costs increase. The pumping cost increase causes the expansion path, pseudoscale line for water and annual quantity of water available to shift to the left, as shown in Figure 5. In a relative sense, if pumping costs are increasing much more rapidly than well yield is declining, it is possible for annual capacity to be sufficient to produce at the intersection of the pseudoscale lines for x_1 and x_2.

Improved Technology

Improved technology can be a means by which per unit production cost can be reduced. Two types of improved technology are considered, along with their potential effect upon production costs. The first type increases total production at each level of variable resource applied, as shown in Figure 6. In this case, the total product curve shifts upward as a result of improved technology. Assuming per unit resource costs to be constant, the variable cost curve shifts to the right (Beattie and Griffin 1975). The per unit variable cost of production is reduced. These variable cost savings must then be weighed against the investment required for the technology to determine if the new technology is economically feasible.

Another type of improved technology is one that

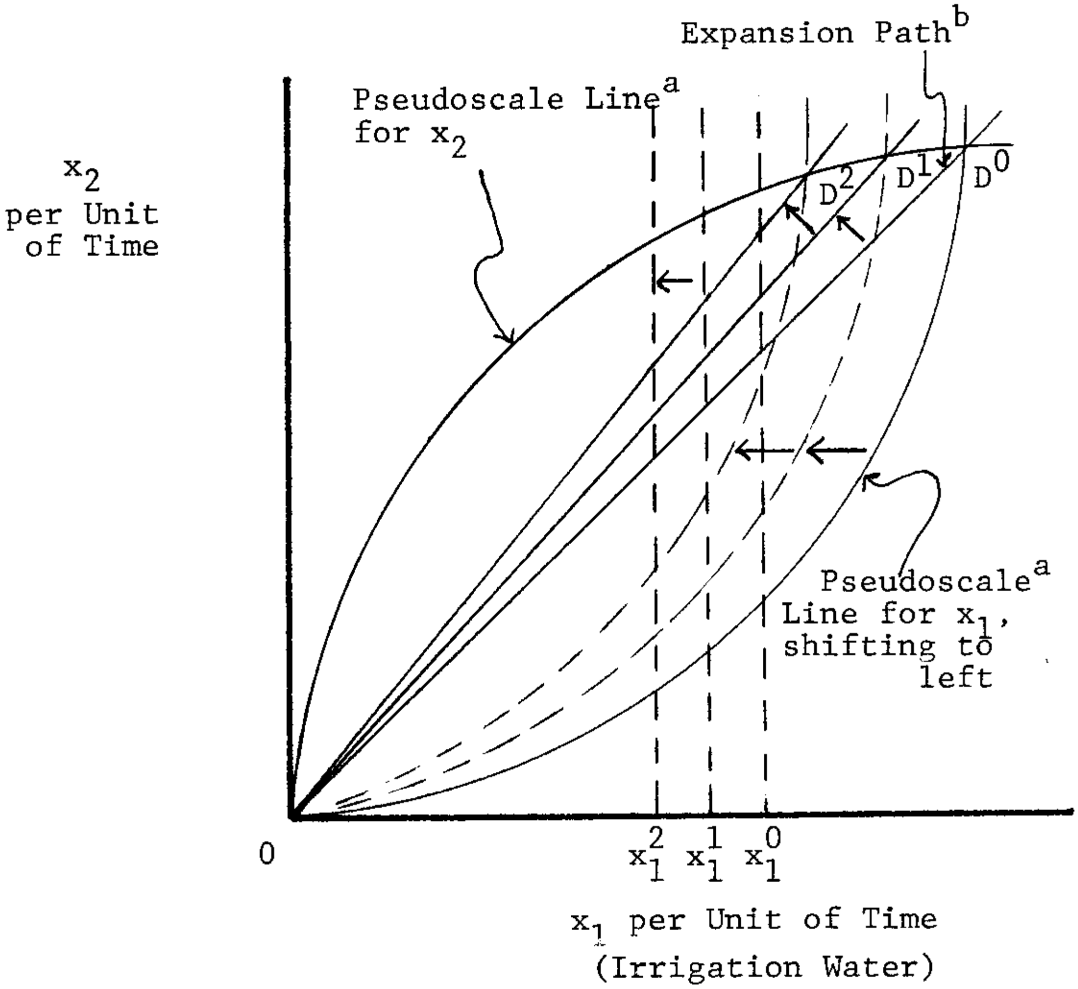

Figure 5. Impact of increased pumping lift and reduced well yield on the pseudoscale line for irrigation water.

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[a] The pseudoscale line is a locus of points along which

$$\frac{MVP_{x_i}}{P_{x_i}} = 1$$

[b] The expansion path (least-cost combinations) is a locus of points along which $\frac{MPP_{x_1}}{P_{x_1}} = \frac{MPP_{x_2}}{P_{x_2}}$

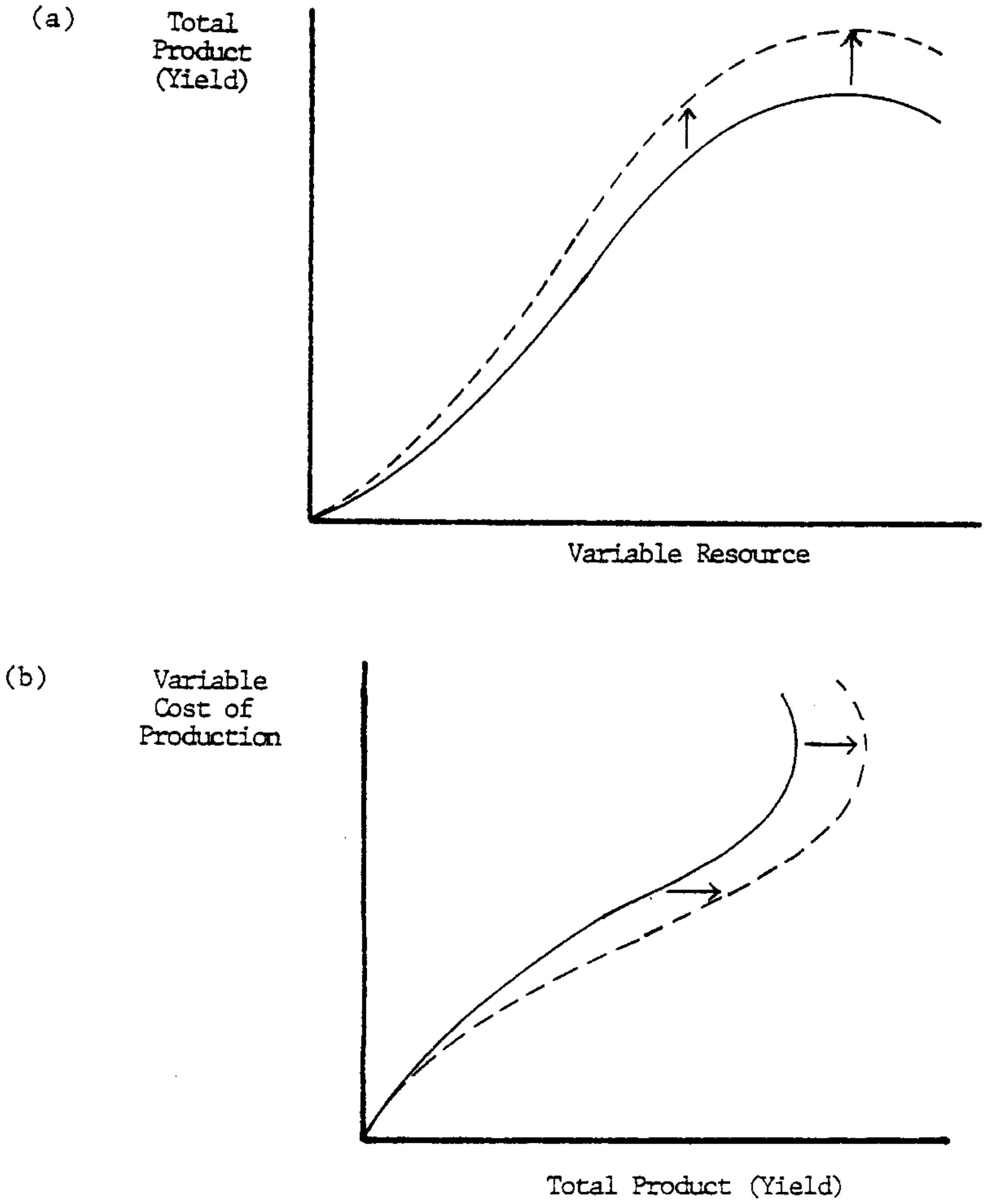

Figure 6. Technology which increases yields at each level of resource input and the effect of this type of technology on variable costs of production.

maintains total production or yields with reduced levels of inputs. The effect of this type of technology on total product is shown in Figure 7. Technology shifts the total product curve to the left, and there is a corresponding shift downward of the variable cost curve (assuming per unit resource cost remains constant). Once again, the savings in variable cost must be compared to the investment required for the new technology to determine its economic feasibility. This last type of technology can be of benefit even if average production costs are not lowered. If the technology is one that conserves an exhaustible resource, such as irrigation water, then the technology can result in irrigation being extended further into the future.

Application of Economic Theory

Certain applications will now be made of economic theory developed in previous pages, primarily to demonstrate how economic concepts bear upon the allocation of resources used in production.

Various changes in technical and economic conditions result in adjustments in commodities produced, levels of production, resource allocations, and levels of resource use. Specifically, the study will consider some adjustments related to (1) changing product price(s), (2) demand for variable resources, (3) changes in technology, and (4) improved efficiencies.

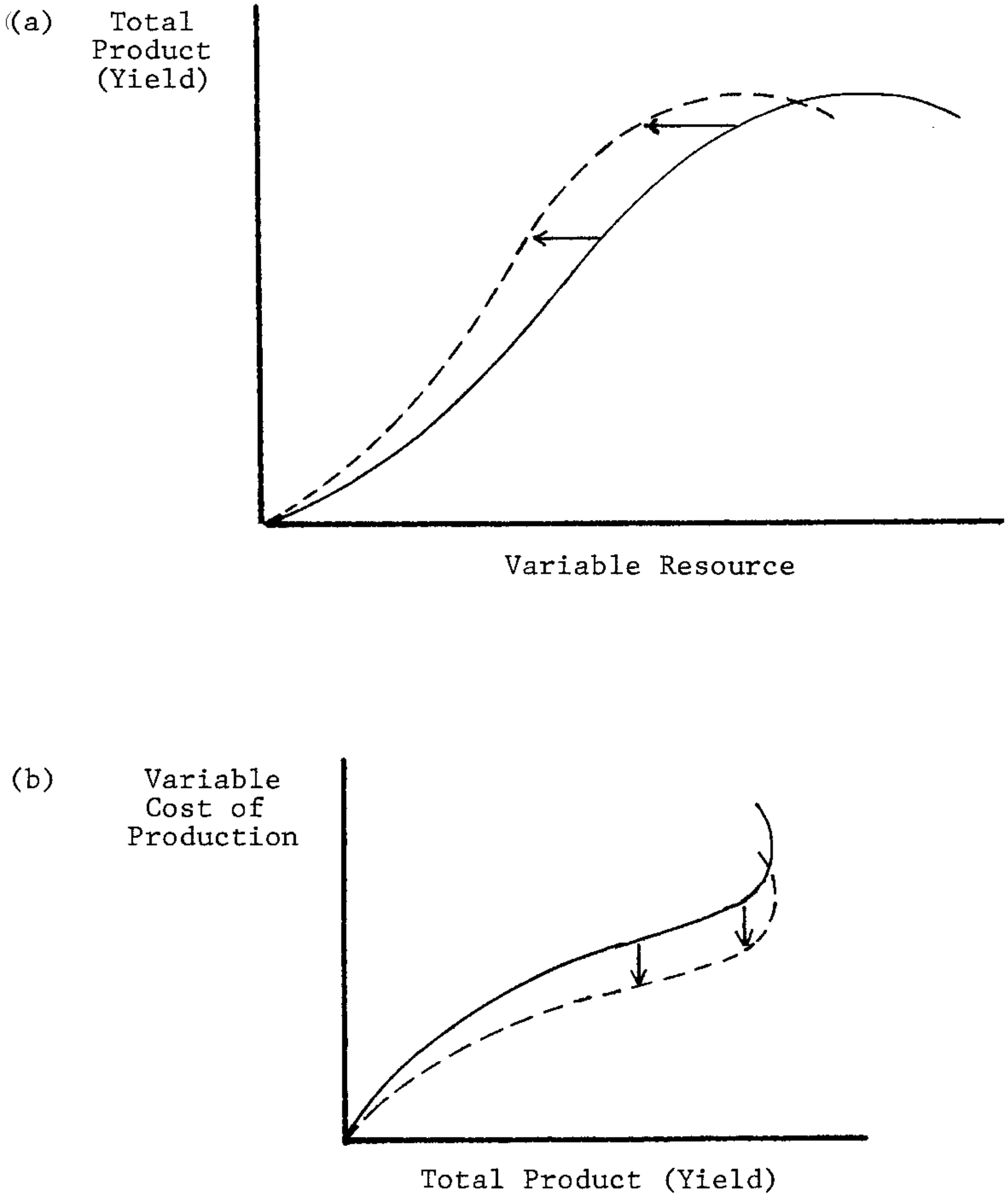

Figure 7. Technology which decreases required levels of input to maintain yields and the effect of this type of technology upon variable costs of production.

In irrigated agriculture, production functions for individual crops have been developed to estimate yields for alternative levels of irrigation. Such functions, if realistic, can be useful in economically allocating irrigation water between competing crops and in determining the proper economic level of irrigation for each crop. Production function theory will be developed in the following theory applications.

Price Adjustments

Assuming one product and two variable resources, an increase in the product price (P_y) results in an increase in marginal value of product (MVP) for both x_1 and x_2 ($MVP_{x_i} = P_y \cdot MPP_{x_i}$). An increase in product prices would encourage higher levels of use of both variable resources to maximize profits. In the case of one of the resources being fixed (e.g., the annual supply of irrigation water), the increased product price would result in increased usage of the variable resource. Total output would be expanded in both cases.

The case was previously stated in which the total water supply was fixed and exhaustible. But there is some discretion as to the temporal allocation of water. The water supply available in the current year could be increased either by drilling additional wells or producing existing wells more intensively. In such a case, increases in current crop prices might encourage a farmer to increase current levels of water usage consistent with the economic allocation concept expressed in equation (3). Referring to Figure 4, water (x_1) would be increased from x_1^0 level to some higher level, assuming well capacity permits. This would be accompanied by increase(s) in variable inputs (e.g., labor and fertilizer) and thus total output would be increased.

Internal adjustments can be expected in response to an increase in the price of natural gas. Treating irrigation labor as complementary to natural gas (used as irrigation fuel), an increase in the price of natural gas would reduce not only the quantity of natural gas demanded but the quantity of irrigation labor as well. Internal adjustments might also include a shift from crops with high water requirements to crops which require less water. If this occurred, there could be further adjustments, such as a reduction in levels of fertilizer. Hence, an increase in the price of an input can have an effect far beyond simply a decrease in the quantity demanded of that input.

Credit as an Input

Many Texas High Plains farmers rely upon credit (the ability to borrow) as a source of funds to pay operating expenses, make investments, and to cope with emergencies (Hopkin, Barry, and Baker 1973). The decision facing the producer as to how much he should borrow is an economic one and is illustrated in Figure 8. The horizontal axis shows the credit available (as a percent). The vertical axis indicates the value of credit used in borrowing or held in reserve. The marginal value of credit (MVP_c) is the marginal value of product (MVP) from additional units of resources and resource services acquired with borrowed funds. The MVP of credit (MVP_c) can be considered as the opportunity cost of unused credit (credit reserve). Unused credit is important as a source of liquidity, and remaining units of unused credit become increasingly valuable. In Figure 8, the U curve measures the interest rate (i_0), shown as a constant, plus the liquidity value of the remaining units of unused credit. Borrowing would occur at OA level ($MVP_c = U$). The greater the value placed on liquidity by the borrower, the more steeply inclined will be the U curve, and the level of borrowing would be reduced. A steeply inclined U curve would indicate that the borrower has a high risk aversion, and he would be restricting his borrowing by choice (where MVP from borrowing is equal to U). This would constitute internal credit rationing.

External credit rationing (as in the case of a conservative lender) would be illustrated by the right-hand margin intersecting the MVP of used credit where the MVP_c is greater than U curve. Hence, the level of credit used is no longer limited by the borrower's judgement but by credit

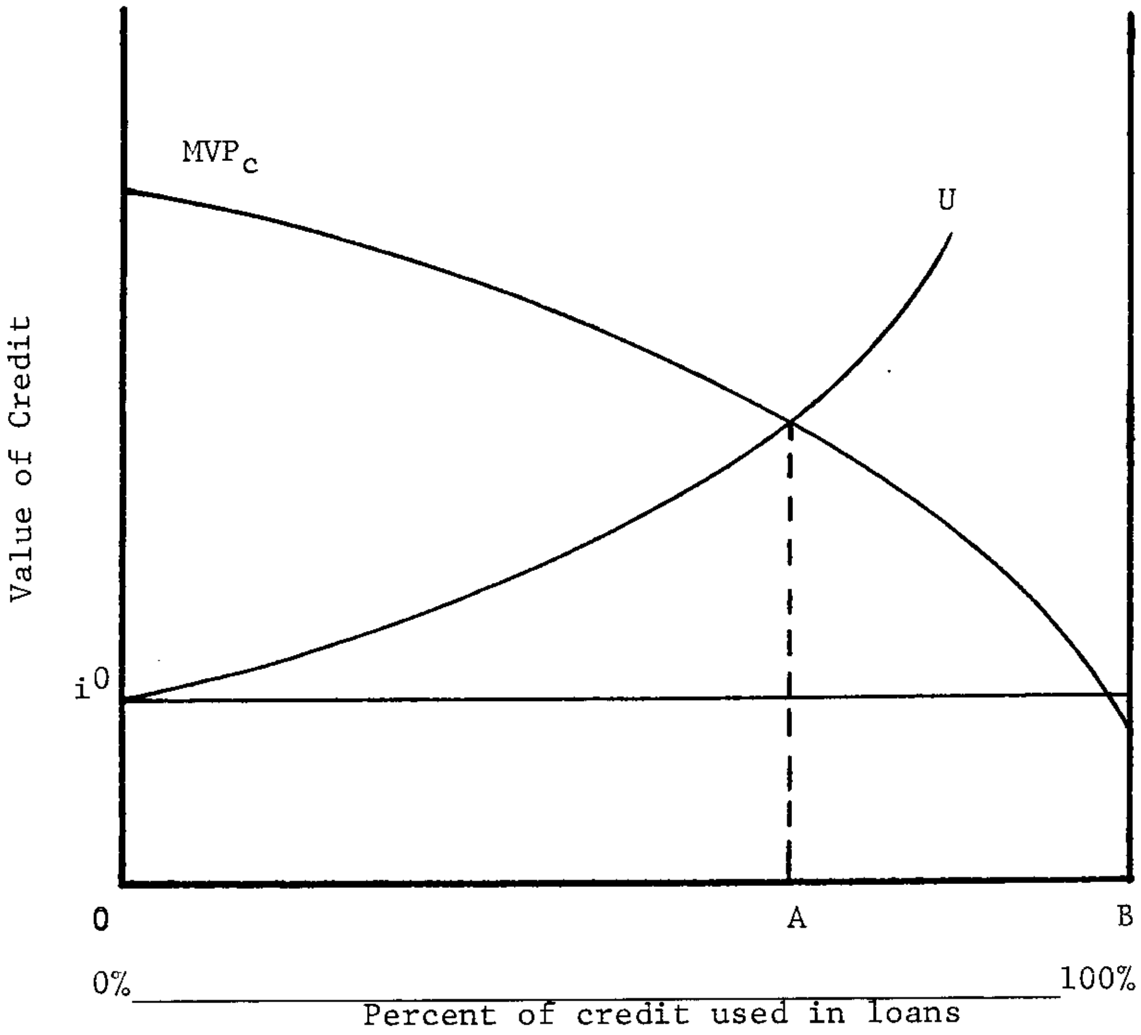

Figure 8. Economic allocation of credit.

Source: Hopkin, Barry, and Baker 1973.

limits established by the lender (Hopkin, Barry, and Baker 1973).

Improved Technology

Improved technology can take many forms. One that has been prevalent is new crop cultivars. For example, hybrid cereal crops, such as corn and grain sorghum already developed, have increased productivity. Figure 6 shows the result of some improved hybrid cereal crops, that at every level of irrigation total product is greater. Additionally, some hybrid cereal crops have achieved yields of earlier cereals but with less irrigation water. Development of other hybrids or crop varieties with even lower water requirements offer one avenue of coping with a declining underground water supply.

Development of more efficient irrigation distribution systems also represents a form of improved technology. A distribution system that applies a greater proportion of total water pumped to the root zone (less evaporation) would reduce the quantity of water needed for irrigation. Figure 7 shows the result of such technology upon total product and variable costs of production. The average product per unit of water applied would be increased. Thus, more efficient use would be made of the limited water supply and would tend to extend the economic life of the water supply. Such a system would also require less irrigation fuel and would, therefore, tend to reduce costs or at least soften the impact of rising irrigation fuel prices.

In the same context, development of low pressure distribution systems would tend to reduce irrigation fuel required per unit of water pumped. By incorporating improved distribution efficiency with low pressure, the economic life of the water supply may be extended. Of course, initial investment and degree of fuel and water savings would ultimately determine the economic viability of any such technologies.

Improved Efficiencies

Improved efficiencies of (1) wells and (2) pumping plants can also have an important bearing upon the water availability and allocation. A well properly designed and equipped can result in higher well yields and reduced costs of maintenance and repairs for the pumping unit. And appropriate pumping plants (which fit the characteristics of the well) can pump water at lower costs per unit of water pumped. In times when irrigation fuel was inexpensive, efficiency of the pumping plant was not a crucial issue, but as the costs of irrigation climb, efforts to improve pumping plant efficiencies can significantly reduce fuel requirements and can help in offsetting higher irrigation fuel prices.

Linear Programming and Marginal Analysis

Production economics focuses on how to best allocate scarce resources in the production process. The chapter thus far has dealt with the allocation of resources according to marginal theory of economics. Linear programming is now introduced as a method by which economic theory will be applied. Linear programming is a method by which a linear objective function can be optimized (maximized or minimized) subject to certain linear constraints (Agrawal and Heady 1972). More specifically, linear programming will be used to select the crop alternatives that will maximize annual net returns subject to resource constraints. Linear programming bears some similarities and differences to marginal analysis.

The principal difference between the assumptions of marginal analysis of the firm and linear programming models of the firm is in the difference between the definition of the production function and an activity. Following is a description of the production function and that of an activity.

> "The activity of linear programming is a more specifically defined concept than the production function of marginal analysis. Indeed, a production function is a family of activities which use the same inputs. If on two points of a production function the ratios of the inputs and outputs are the same, they represent different levels of the same activity.

> Otherwise, they represent different activities. But the production function fails to consider the parallel or joint use of several activities in producing a product--a common feature of modern industry." (Dorfman 1953).

Hicks (1968) compares the assumptions underlying marginal analysis and linear programming. The following are assumptions which apply to Hick's marginal analysis model and a linear programming model:

(1) The state of technology is predetermined by technical considerations.

(2) The prices of the firm's products and productive input prices are known and constant, i.e., perfect competition.

(3) Complete certainty prevails concerning product and input prices and parameters determining the production function.

(4) Marginal analysis is static, i.e., no changes occur in product and input prices or production function parameters.

For marginal analysis, the production function is assumed to be continuous, with non-zero first and second degree partial derivatives. The firm's production function is characterized by a decreasing marginal rate of substitution between any two products. In contrast, each activity of a LP model is characterized by constant input-output ratios which are independent of their level of use (constant returns within activities).

With marginal analysis, the firm seeks to maximize a profit function subject to the technical constraints of the firm's production function. With linear programming, the firm seeks to maximize a linear profit function subject to constraints imposed by the nature of its activities and the available quantities of inputs. In addition, it is assumed that all the firm's inputs and products are perfectly diviible and that additivity prevails among activities and their use of inputs. With two or more simultaneous activities, total product is the sum of the products produced by each activity separately, and the quantities of inputs required are the sums of the requirement for each separate activity (Hicks 1968).

Although each activity is characterized by constant returns within each activity, it is possible, using a series of linear activities, to approximate a production function which is characterized by diminishing marginal returns, i.e., decreasing marginal product (Naylor and Vernon 1969). For example, Figure 9 represents a production function for irrigation water. The production surface OABC can be approximated by three activities. Segments OA, OB, and OC represent these activities of increasing levels of irrigation. Linear programming can, in this manner, employ the concepts of the production function and marginal analysis. This, plus the feature that linear programming can be applied to

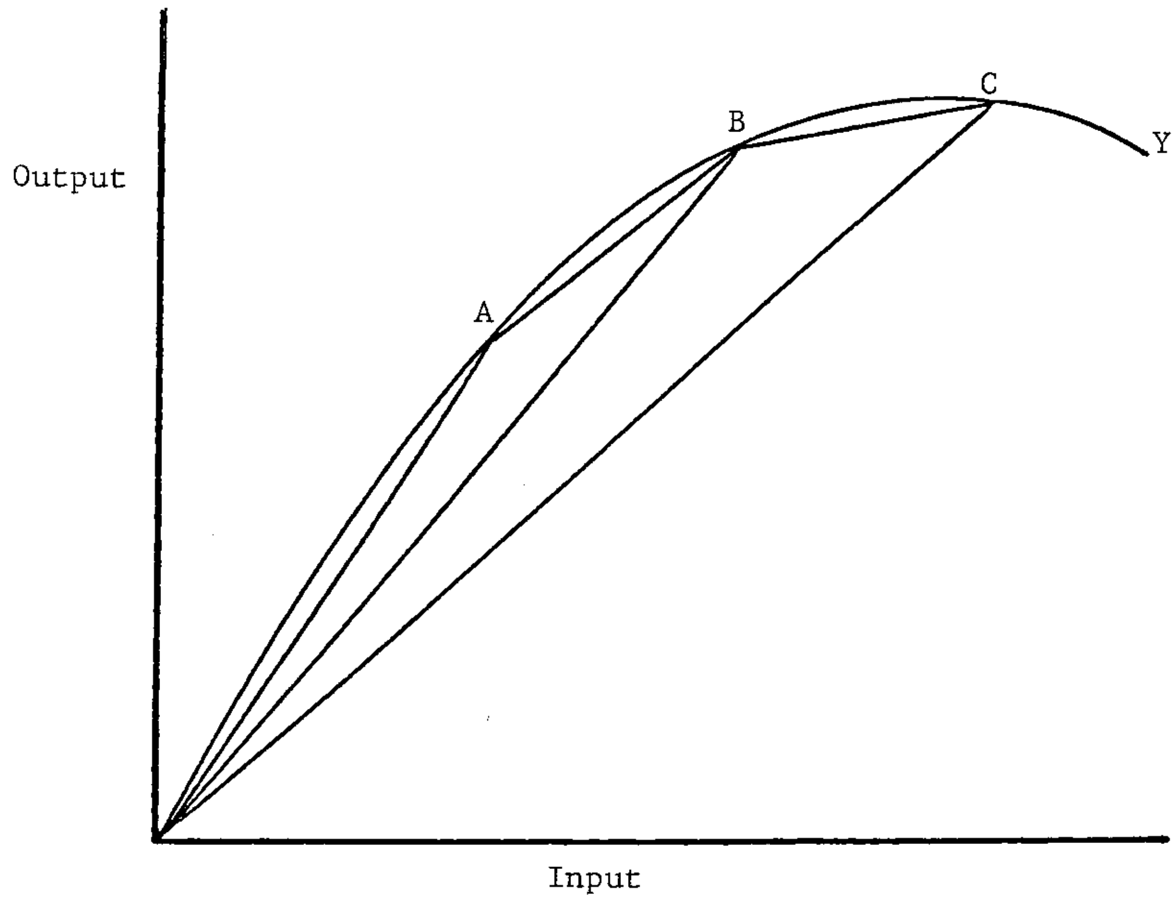

Figure 9. Diminishing returns in linear programming.

Source: Naylor and Vernon 1964.

multi-product, multi-factor problems, make linear programming techniques useful in allocating the farm firm's limited resources in the production process.

CHAPTER IV

METHODS AND PROCEDURES

This chapter outlines the methods and procedures used as well as presenting the data base of the study. The primary emphasis is on the analytical model and methods employed to apply the model to address alternative issues.

Assumptions

Basic assumptions underlie the model and analysis. Some of these assumptions are as follows:

1. A typical farm situation including average management.
2. Maximization of annual net returns by the operator.
3. Constant production technology over time, except when explicitly changed.
4. That 1978 product and factor prices prevail over time, except when evaluating the effects of selected price changes.
5. Well yield; i.e., gallons per minute (gpm), is a function of saturated thickness of the aquifer.
6. Maximum well yield is 800 gallons per minute (gpm) and is based on the average well in the region, not aquifer yield potential.
7. The specific yield of the aquifer is 15 percent (Cronin 1961).
8. Specific well situations include initial lifts of

75, 175, and 250 feet.

Typical Farm

Farms in the study area averaged 620 cultivated acres in 1976, of which 422 were irrigated and 198 dryland (New 1976). The typical farm situations evaluated in this study were 640 acres (approximately the average size farm). All 640 acres were considered as subject to irrigation but a dryland option existed for any or all acreage. Soil types and productivity were considered as homogeneous: fine textured and highly productive, characteristic of the study area. Crops typically grown to the south of the Canadian River include corn, cotton, soybeans, grain sorghum, wheat, and wheat grazing by cattle. Furrow systems applied only to the Southern High Plains. To the north of the Canadian River, the colder climate precludes cotton as a feasible production alternative.

Water Resource Situations

Over the study region there is a significant variation in the supply of groundwater available for irrigation. To provide insight into the effect of available groundwater, three alternative water resource situations were specified as shown in Table 4. With the availability of irrigation water and the price of irrigation fuel being important limitations or constraints for the Texas High Plains farmer,

Table 4. Alternative Water Resource Situations Specified for Application of the Model: Texas High Plains.

Water Resource Situation[a]	Saturated Thickness	Lift	Well Depth	Number of Wells[b]
	-----------(feet)		----------	
Good	250	250	500	4
Fair	125	175	300	6
Poor	75	75	100	10

[a] These water resource situations are based upon water resource data from the old Texas Water Development Board, now the Texas Department of Water Resources.

[b] Number of wells applies to the 640 acre farm.

special consideration has been given these factors in the formulation of the model. All applications of the model, both static and temporal, initiate with these water resource situations. Existing water situations on the Texas High Plains are quite diverse. Saturated thickness ranges from less than 50 feet to over 500 feet while depth to water is generally from 50 to 325 feet. The specific water resource situations defined for this study were intended to cover a wide range of existing water situations. Most of the water in storage (86 percent) occurs where saturated thickness is from 50 to 250 feet (Hughes and Harman 1966), which is the range covered by the specified water situations in Table 4. Further, about 80 percent of the water lies at depths ranging from 75 feet to 225 feet. Hence, the water situations specified in Table 4 cover the situations where much of the water occurs.

Analytical Model

The mathematical model developed contains a linear programming (LP) component plus a Fortran component. The LP component can be used (without the Fortran segment of the model) for static analysis. For temporal analysis, the Fortran component is used in conjunction with the LP component. By means of the Fortran sub-routine, basic data are read into the model. Recursive runs of the model can then be made. At the end of each year, the Fortran component recalculates certain coefficients based on water use in the previous year's solution and inputs these new coefficients into the LP component. The new coefficients show adjusted levels of available water and the increased quantities of irrigation fuel and labor required. Both the LP component and the Fortran component are subsequently explained in detail.

Linear Programming Component

Linear programming (LP) provides a means of simultaneously considering a wide range of production possibilities and resource constraints in the process of developing a farm organization. Linear programming is also conducive to analyzing changes in several factors. For example, sensitivity of a farm organization (cropping patterns) to the availability of a scarce resource (e.g., irrigation water), change in the price of a resource or product, or adjustments in input requirements can be readily investigated. Thus, "...the principal advantage of linear programming as the planning method is not that it leads to one foolproof plan, but that it provides a means of analyzing a variety of alternative decisions" (Beneke and Winterboer 1973).

The basic format of the linear programming model developed for this study is initially presented in mathematical notation. The farm net return objective function of the linear programming model is:

$$\Pi = \sum_{j=1}^{m} p_j \cdot y_j - \sum_{i=1}^{n} r_i \cdot x_i \qquad (4)$$

where

Π = annual net returns to fixed resources of the farm;

P_j = the per unit price of the jth commodity produced and sold;

y_j = the number of units of the jth commodity produced and sold;

r_i = the per unit cost of the ith resource used in production;

x_i = the number of units of the ith resource used in production;

m = the number of commodities considered for production;

n = the number of resources used in production.

The objective function (Π) is maximized subject to the following constraints:

$$y_j \geq 0 \tag{5}$$

$$x_i \geq 0 \tag{6}$$

$$a_{ij}y_j \leq b_i \tag{7}$$

where

b_i = the maximum amount of the ith resource available;

a_{ij} = the number of units of the ith resource used in the production of the jth commodity.

Inequalities (5) and (6) avert negative production and negative resource use, respectively, while the inequality (7) prevents more resources from being used than are available.

The linear programming portion of the model for a year (static model) is shown in Table 30, Appendix B. A simplified version of the model is presented in Table 5 to illustrate the basic structure of the LP model.

Table 5. Basic Format of the LP Model Developed for 640 Acres, a Typical Farm: Texas High Plains.

Rows	Production		Purchasing			Fixed Costs		Borrowing		Savings		Selling		Constraints b_i
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	Y_1	Y_2	
Objective function [a]	$-e_1$	$-e_2$	$-r_3$	$-r_4$	$-r_5$	-1	-1	$-i_0$	$-i_0$	r_0	r_0	P_{y1}	P_{y2}	
Production inputs: [b]														
Non-purchased w_1	u_{11}	u_{12}												$\leq b_1$
Non-purchased w_2	u_{21}	u_{22}												$\leq b_2$
Purchased w_3	u_{31}	u_{32}	-1											$\leq b_3$
Purchased w_4	u_{41}	u_{42}		-1										$= 0$
Purchased w_5	u_{51}	u_{52}			-1									$= 0$
Fixed costs: [c]														
Machinery & Equip.	FC_{11}	FC_{12}				-1								$= 0$
Irrigation system	FC_{21}	FC_{22}					-1							$= 0$
Cash flow: [d]														
Period 1	e_{11}	e_{12}	r_{13}	r_{14}	r_{15}			-1		1			$-P_{y_2}$	$\leq b_4$
Period 2	e_{21}	e_{22}	r_{23}	r_{24}	r_{25}			$1+i_0$	-1	$-(1+r_0)$	1	$-P_{y_1}$		$\leq b_5$
Period 3	e_{31}	e_{32}	r_{33}	r_{34}	r_{35}				$1+i_0$		$-(1+r_0)$			$\leq b_6$
Total Credit Limit	e_1	e_2	r_3	r_4	r_5									$\leq b_7$
Sell Y_1 [e]	$-Y_1$											1		$= 0$
Sell Y_2		$-Y_2$											1	$= 0$

[a] The coefficients of the objective function represents cost of production and prices of inputs and products.

[b] The "u" values are the levels of each resource used, both the non-purchased and purchased inputs, in the production process.

[c] For static analysis the values in the objective function for fixed costs would be zero. FC_{ij} represents fixed costs for machinery and equipment for each production activity.

[d] The "e" values represent the cash requirements within each cash-flow time period for all items not included as purchasing activities within the framework of this model. The "r" values identify the amount and timing of cash required for purchasing inputs with purchasing activities. Cash is generated by either borrowing or selling products. The cost of borrowing is i_0, and the earning rate of funds in savings is r_0.

[e] The yield of each crop is indicated under each production activity. Yields of each crop are then transferred to selling activities of the objective function.

Activities

The appropriate number and structure of activities included in a mathematical model are a function of the research objectives. The model developed herein for a typical High Plains farm contains 185 activities, shown in Table 30, Appendix B, and includes irrigated and dryland production activities for cotton, grain sorghum, and wheat and irrigated activities for corn and soybeans. Along with the wheat, a stocker-cattle grazing alternative was incorporated. With sprinkler irrigation, cotton was not included as a crop alternative. This was because cotton has not been traditionally produced with sprinkler irrigation.

A furrow distribution system and a center-pivot distribution system were included as alternatives for applying irrigation water. With furrow irrigation cotton was included as a crop option, and the results of these model applications apply only to that part of the area to the south of the Canadian River. A shorter growing season to the north of the river renders cotton to be economically infeasible.

Results of the model with sprinkler irrigation can apply to the entire study area. Additionally, results with Poor water apply only to that part of the study area to the south of the Canadian River since that water situation is not typically found to the north of the river. In addition to the basic production activities, there are (1) separate purchasing activities for selected inputs, (2) selling activities for products produced, and (3) borrowing and repaying activities for cash flow by two-month time periods.

All labor, including that of the farm operator, is purchased within six labor periods. Herbicides and insecticides are purchased as needed and applied by custom operators. In addition, the crops are harvested by custom operators. For the stocker grazing alternative on wheat, the model includes the option of purchasing cattle and grazing them or leasing wheat pasture to others. There are also options for grazing wheat until March 7th, then harvesting the wheat for grain in June, or grazing out wheat, leaving no wheat to harvest for grain.

Since natural gas is the primary irrigation fuel used, it is included in the model as a separate activity where quantity used is purchased. This facilitates the evaluation of the effects of gas price adjustments. Natural gas is used as the irrigation fuel until the well yield declines to 150 gpm, where internal combustion engines (as fueled by natural gas) are inefficient, thus resulting in high costs per unit of water pumped (Shipley 1977). Below 150 gpm the model is designed to reflect pumping costs from a submersible pump powered by electricity.

Model construction is such that operating funds are either borrowed or derived from the sale of crops produced in that year of analysis. However, it is assumed that the operator had on hand at the beginning of the year sufficient funds to provide for his living expenses. Borrowing of operating capital is separated into six periods. All borrowed funds are repaid at the end of each credit period, either by selling crops or by borrowing from the following credit period, and at the end of the year all borrowed operating funds are repaid. Further, in the recursive framework there is no provision for carryover of the year's net returns to be used in the subsequent year for operating expenses. As a simplifying assumption, it was assumed that any carryover earnings would be used in the subsequent year for consumption, capital expenditures, or taxes. This approaches the real world behavior of many farmers. Also, since this was not a growth model it was not considered to be a critical assumption. An interest rate of 10 percent is assumed for the typical farmer for operating capital, and it is further assumed that any excess funds the farmer might have on hand can be invested in a savings account at an annual rate of five percent (Cary 1978, Potts 1978). At the end of a year, net returns are tabulated and stored as the model moves to the subsequent year.

Data Requirements

Basic requirements for the linear-programming matrix include: (1) resource requirements, (2) crop yields for various levels of irrigation and specified inputs, (3) variable costs of machinery and equipment, (4) fixed costs of machinery and equipment and both center-pivot sprinkler and furrow irrigation distribution systems, (5) prices of selected inputs purchased, (6) prices of crops and cattle sold, and (7) resource availability, i.e., constraints. Much of the data related to resource requirements and variable costs was derived from 1978 crop enterprise budgets developed by the area economists of the Texas Agricultural Extension Service (Extension Economist-Management). The requirements for natural gas and electricity for irrigation are calculated external to the LP model and are explained subsequently. Crop-yield estimates were obtained primarily from statistical production functions estimated for the study area (Shipley 1977a). These production functions for corn, grain sorghum, and wheat and their graphs are shown in Figures 18 through 20 in Appendix C. Crop yields are shown as a function of irrigation water applied with furrow irrigation. The same functions were used to estimate yields with sprinkler irrigation, based on the premise that two inches of sprinkler applied water is the equivalent of three inches applied by furrow (Shipley 1977a). Because cotton and soybeans have not traditionally been produced with sprinkler irrigation, they were not included as options. Estimates of crop yields at alternative levels of irrigation could not be taken from crop budgets prepared by Extension Economists because their budgets included only one level of irrigation per crop.

Vital information was provided by the following staff members at the Amarillo Center. John Shipley provided estimates of soybean yields for different levels of irrigation. Additionally, he provided information relative to the proper timing of irrigation applications for all the crops (Shipley 1977a). Ray Sammons provided information relative to labor requirements (1978). Frant Petr (1977) made recommendations regarding fertilizer applications, while Allen Wiese (1977) specified herbicide requirements. Insecticide requirements were provided by Shipley (1977) and Igo (1977).[6] Table 6 shows the irrigated production activities, the accompanying levels of irrigation water and nitrogen fertilizer applied, and the respective yields.

Basic input prices used were those which prevailed in 1978 (Table 7). Generally, target prices were used for crops sold. There were no target prices for soybeans and beef, hence, the average market price was used. For soybeans, an average price for the previous three years was used (Texas Crop and Livestock Reporting Service 1977). Cattle prices were based upon average prices for January-August 1978.

Constraints

Constraints included in the model are (1) acres, (2) available water, divided into irrigation periods ("critical water periods"), (3) labor, divided into labor periods, and (4) credit divided into credit periods. The constraints are shown in Table 8.

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[6] Igo is a custom farm operator and is not associated with the Southwestern Great Plains Research Center.

Table 6. Summary of Irrigated Production Activities, Levels of Irrigation Water, Nitrogen Fertilizer, and Yields Used in the LP Model: Texas High Plains.

Production Activities	Irrigation Water (inches[a])	Nitrogen Fertilizer (lbs.)	Yields (bu. or cwt.[b])
	(per acre)		
Sprinkler Irrigated			
Corn[b]			
(PP+2)	10	120	93.0 bu.
(PP+3)	16	145	132.0
(PP+4)	20	170	148.0
(PP+5)	24	200	156.0
Sorghum			
(PP only)	2	50	21.0 cwt.
(PP+1)	4	80	28.5
(PP+2)	8	120	50.0
(PP+3)	12	140	63.0
(PP+4)	15	160	67.5
Wheat for Grain			
(PP only)	3	40	16.0 bu.
(PP+1)	5	80	25.5
(PP+2)	7	120	34.0
(PP+3)	9	140	41.0
(PP+4)	11	160	46.5
Wheat with Grazing			
(PP only)	3	40	14.5 bu.
(PP+1)	5	80	23.0
(PP+2)	7	120	30.5
(PP+3)	9	140	37.0
(PP+4)	11	160	42.0
Furrow Irrigated			
Corn			
(PP+2)	15	120	81.0 bu.
(PP+3)	19	145	106.0
(PP+4)	23	170	126.0
(PP+5)	27	200	141.0
(PP+6)	31	230	151.0

Table 6. (continued)

Production Activities	Irrigation Water (inches[a])	Nitrogen Fertilizer (lbs.)	Yields (bu. or cwt.[b])
	------------(per acre)	------------	------------
Furrow Irrigated (cont'd)			
Cotton			
(PP only)	7	0	3.50 cwt.
(PP+1)	11	0	4.25
(PP+2)	15	40	5.00
(PP+3)	19	40	5.25
Sorghum			
(PP only)	7	40	21.0 cwt.
(PP+1)	11	80	40.0
(PP+2)	15	120	54.0
(PP+3)	19	140	63.0
(PP+4)	23	160	67.0
Soybeans			
(PP+2)	15	0	37.0 bu.
(PP+3)	19	0	43.0
(PP+4)	23	0	49.0
Wheat for Grain			
(PP only)	5	40	19.0 bu.
(PP+1)	9	80	31.0
(PP+2)	13	100	43.0
(PP+3)	17	120	51.0
Wheat with Grazing			
(PP only)	5	40	17.0 bu.
(PP+1)	9	80	28.0
(PP+2)	13	100	39.0
(PP+3)	17	120	46.0

[a] The inches of water are based upon production functions and recommendations by John Shipley (1978).

[b] Cwt. refers to 100 pound weight.

[c] PP+2 indicates one pre-plant plus two post-plant waterings, etc. The number of irrigations is an approximation for each crop and water rate.

Table 7. Base 1978 Prices for Crops and Inputs Used in the Analysis: Texas High Plains.

Item	Unit	Price
Crop Prices [a]		
Corn	bu.	2.10
Cotton lint	lb.	.48
Cotton seed	ton	80.00
Grain sorghum	bu.	4.25
Soybeans	bu.	5.00
Wheat	bu.	3.40
Wheat pasture	aum. [b]	12.50
Feeder cattle, lightweight	lb.	.56
Feeder cattle, heavyweight	lb.	.52
Savings	dollar	.05
Input Prices		
Natural gas	mcf	1.50
Electricity	kwh	.032
Labor, full-time	hour	4.50
Labor, part-time	hour	4.00
Cotton insurance	dollar	.12
Wheat insurance	dollar	.08
Corn seed	lb.	.90
Cotton seed	lb.	.32
Grain sorghum seed	lb.	.45
Soybean seed	lb.	.08
Wheat seed	bu.	7.50
Atrazine	acre	3.50
Treflan	acre	3.50
Propazine	acre	3.00
2,4-D	acre	3.00
Furidan	acre	3.00
Malathion	acre	3.00
Methyl-Parathon	acre	3.50
Nitrogen (anhydrous)	lb.	.16
Phosphorous	lb.	.30
Diesel	gal.	.50
Gasoline	gal.	.50
Custom application of herbicides or insecticides	acre	2.50

Table 7. (continued)

Item	Unit	Price
Input Prices (cont'd)		
Custom Combine of:		
Corn	bu.	.30
Grain sorhgum, dryland	acre	7.00
Grain sorghum, irrigated	bu.	.30
Soybeans	acre	10.00
Wheat, dryland	acre	7.00
Wheat, irrigated	acre	8.70
Cotton stripping and hauling	cwt.[c]	1.00
Cotton ginning	cwt.	1.25
Custom hauling of:[d]		
Corn	bu.	.05
Grain sorghum	bu.	.10
Soybeans	bu.	.10
Wheat	bu.	.10
Corn drying	bu.	.10
Stocker cattle	lb.	.64
Borrowed operating capital	dollar	.10

[a] Crop prices are 1978 target prices. Cotton target price is adjusted downward for quality.

[b] Animal Unit Month is the equivalent of grazing a 1000 pound cow for one month.

[c] One-hundred pounds of seed cotton or cotton that includes the lint, seed, burr, and other trash delivered to the gin.

[d] The hauling rates were based on an average distance of 15 miles to grain elevators.

Table 8. Resource Constraints Specified for 640 Acres, a Typical Farm: Texas High Plains.

Resource	Unit	Quantity Available per Time Period
Cropland		
Dryland	acre	640
Sprinkler irrigated	acre	640
Furrow irrigated	acre	640
Total cropland	acre	640
Water supply [a]		
Period 1 (Jan-Feb)	acre-feet	891
Period 2 (March)	acre-feet	445
Period 3 (April)	acre-feet	445
Period 4 (May)	acre-feet	445
Period 5 (June)	acre-feet	445
Period 6 (July)	acre-feet	445
Period 7 (Aug)	acre-feet	445
Period 8 (Sept)	acre-feet	445
Period 9 (Oct)	acre-feet	445
Period 10 (Nov-Dec)	acre-feet	891
Labor [b]		
Period 1 (Jan-Feb)	hours	243.4
Period 2 (Mar-Apr)	hours	327.0
Period 3 (May-June)	hours	464.9
Period 4 (July-Aug)	hours	477.3
Period 5 (Sept-Oct)	hours	382.1
Period 6 (Nov-Dec)	hours	292.2
Credit		
Period 1 (Jan-Feb)	dollars	$15,000[c]
Period 3 (May-June)	dollars	45,000
Period 4 (July-Aug)	dollars	58,000
Period 5 (Sept-Oct)	dollars	70,000
Period 6 (Nov-Dec)	dollars	80,000
Total credit	dollars	150,000[d]

[a] The water available during the critical water periods is for the Good water resource situation for the first year of analysis. These values change as the saturated thickness changes since well yields adjust.

[b] Labor and credit constraints are not always used. Labor is based on the operator and one full-time employee.

[c] The credit limits for the respective credit periods were determined from the author's experience in the financial community and in private communications with J. B. Potts.

[d] An initial total credit limit of $150,000 was used and was reduced parametrically to a low of $30,000.

Water availability is separated into ten water periods referred to as "critical water periods".[7] Each of these critical water periods was one month, except from November through February. Because irrigation activity in these months was minimal, January and February were included as one critical water period, as were November and December. The amounts of water available in each of the critical water periods is a function of well yield (gpm) and the average number of days in each watering period not used for repairs. For this study, it was assumed that an irrigation well could potentially pump 26 days a month.

Labor, except for part-time labor for hoeing, is limited to two men, the operator and one full-time employee. The hours worked per day, which is a function of the season, is low in January and February (due to winter weather and fewer hours of sunlight) and high in June and July (due to warm weather and more hours of sunlight). No additional labor could be purchased, except for part-time hoeing labor. Labor required for machinery and irrigation is divided into six labor periods for the year. Due to the great variation in labor requirements between periods, labor could prove to be constraining for some labor periods but not for others and not for the yearly requirements. Machinery constraints are not directly considered in the model, but limits on

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[7] Water is applied to the various crops during periods that are critical to the growth and production requirements of the respective crops (Shipley 1977b).

machinery are indirectly considered through the labor constraints.

Credit is included in the model for selected periods (credit periods) of the year on a total annual basis, i.e., for the entire year. Borrowing takes place within the credit periods, and a borrowed amount can be transferred from one credit period to the next, with interest added at the time of each transfer. A 10 percent annual interest rate is charged on all borrowing. Further, as crops are sold, receipts from the sales are used to pay off the loans, including interest charges. All crop receipts left after paying off loan balance are deposited in a savings account and earn interest at an annual rate of 5 percent.

Credit can be rationed externally, as by a lender, or rationed internally by the farmer. External credit rationing might prove to be disruptive to a farmer's operations, impacting upon the farmer's net returns, and possibly threatening his economic survival. Conversely, the farmer might elect to restrict or limit the amount of credit he uses, preferring to maintain a credit reserve which would provide a source of liquidity. The liquidity thus achieved enables the farmer to meet unexpected emergencies or investment opportunities. By parametrically reducing the total credit limits, the effects of either internal or external credit constraints upon net returns can be observed. Valuable credit reserves could perhaps be maintained without seriously reducing net returns. A given decrease in net returns resulting from a given decrease in credit used (an increase in credit reserves) can be treated as the cost of maintaining that credit reserve. In addition, shadow prices are used as measures of reservation prices on credit reserves (Barry and Baker 1971).

Fortran Component

In addition to using the model for annual evaluations, it can be set in a recursive framework to make a temporal analysis by linking it to a Fortran program. Recursive linear programming is defined as the following:

> "Recursive linear programming generates an optimal solution based on one time period. Unlike the single-period form, the recursive model is updated based on the optimal solution of the preceding time period and optimized again for successive time periods. The formulation implies perfect knowledge for one time period and uses past experience in developing plans for succeeding periods. Perfect knowledge means that prices, yields, costs, and other variables are known at the beginning of each period" (Lins 1968).

Recursive applications of the model were appropriate because groundwater was declining with each year's use, requiring that irrigation fuel requirements and available water be recalculated for each year of irrigation.

An important feature of the recursive model is that the Fortran program functions as a sub-routine of the LP model. For the temporal analyses, the Fortran program performs the following tasks:

1. Calculate the decrease in saturated thickness and

the related increase in pumping lift based upon the quantity of water pumped from the aquifer during the previous year.

2. Calculate the change in well yield (gpm) based on the estimated change in saturated thickness of the aquifer for each year.
3. Calculate the change in energy required to pump an acre foot of water based on the increased pumping lift and change in well yield for each subsequent year.
4. Calculate for each succeeding year the maximum quantity of irrigation water available in each "critical water period" based upon the adjusted well yield.
5. Alter the LP tableau for the changing water resource situation and corresponding effect on irrigation energy requirements.
6. Calculate the present value of the income streams to the farm plan and to the water supply.

The Fortran program includes the following equations which are used to annually update the LP component. Aquifer depletion is calculated as follows:

$$D = W_{t-1} / (.15 \cdot CA) \qquad (8)$$

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 for the farm (includes non-cultivated and dryland).

The well yield corresponding to the reduced water-bearing sand is given by:

$$GPM_t = GPM_0 \text{ if } ST_t/ST_0 \geq .83667 \tag{9}$$

else

$$GPM_t = 1.14 \cdot (ST_t/ST_0)^{0.71} \cdot GPM_0 \tag{10}$$

where

GPM_t = well yield in gallons per minute in the current year;

GPM_0 = original well yield in gallons per minute is assumed to be 800 gpm for this analysis;

ST_0 = original saturated thickness of the aquifer is assumed to be 250 feet;

ST_t = saturated thickness of the aquifer in the current year.

With original well yield set at 800 gpm and original saturated thickness set at 250 feet, well yield for any situation is a maximum of 800 gpm and is maintained to a saturated thickness of 209 feet, after which the well yield declines according to equation (10). Although potential well yield of the aquifer is much greater, this relationship approximates the typical well for the Texas High Plains (Reddell 1977).

Natural gas required to pump a specified well yield from a given depth for the appropriate distribution system is taken from Kletke, Harris, and Mapp (1978) and is:

$$NG_t = (.022L_t + .053PSI)/PE \qquad (11)$$

where

NG_t = natural gas required to pump one acre-foot of water in the current year;

PSI = water pressure required (in pounds per square inch);

L_t = pumping lift (in feet) in current year;

PE = pump efficiency.

Thus, with well yield, water availability in any selected period is established by:

$$M = .0044 \quad GPM_t \cdot T \cdot W \qquad (12)$$

where

M = the maximum acre-feet of water that can be pumped within a specified period of time;

GPM_t = well yield in gallons per minute in the current year;

T = the days available for pumping in a specified period of time;

W = the number of wells.

The basic operation of the recursive model is shown in Figure 10. Basic data (shown in Table 9) are first read into the model through a Fortran sub-routine. The data read into the computer designate the situation for that particular computer run. At the termination of a specified computer run the temporal analysis is summarized in tabular form. Table 10 shows an example of a printout which, for the benefit of the researcher, shows a description of the specific

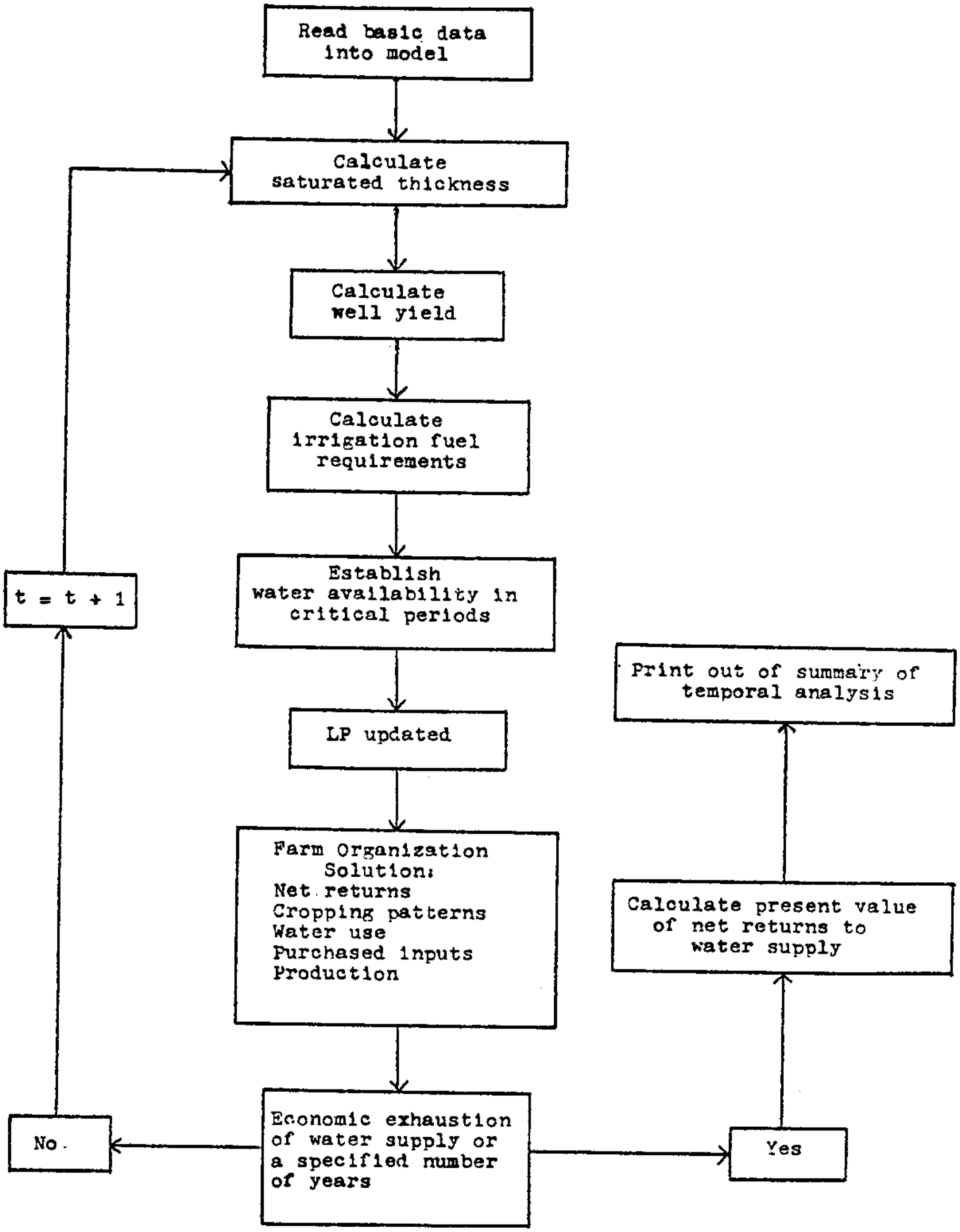

Figure 10. Operational flow of the recursive linear programming model.

Table 9. Basic Input Data to the LP Model from the Fortran Component When Applied in a Recursive (Temporal Analysis) Framework. [a]

Items	Units
Product prices	dollars
Purchased input prices	dollars
Total acres	acres
Number of wells	wells
Beginning saturated thickness	feet
Beginning lift	feet
Pump efficiency	percent
Drive efficiency	percent
Dryland net returns	dollars
Planned years of analysis	years

[a] In addition, the type of irrigation distribution system is specified, whether furrow or center-pivot sprinkler system.

Table 10. An Example of Model Printout Summarizing a Specified Temporal Analysis.

Item	Unit	Value
Prices		
Cotton Lint	$/lb.	0.48
Cotton Seed	$/ton	80.00
Corn	$/bu.	2.10
Grain Sorghum	$/cwt.	4.25
Soybeans	$/bu.	5.00
Wheat	$/bu.	3.40
Stockers	$/lb.	0.64
Light Feeders	$/lb.	0.56
Heavy Feeders	$/lb.	0.52
Natural Gas	$/mcf.	1.50
Electricity	$/kwh.	0.03
Diesel	$/gal	0.50
Gasoline	$/gal	0.50
Nitrogen	$/lb.	0.16
Phosphorous	$/lb.	0.30
Irrigation Labor	$/hr.	4.50
Machinery Labor	$/hr.	4.50
Hoe Labor	$/hr.	4.00
Cropland	acre	640.00
Sprinkler Irrigated	acre	640.00
Furrow Irrigated	acre	0.00
Contributing to Irrigation	acre	920.00
Wells	no.	10.00
Beginning Saturated Thickness	feet	75.00
Beginning Depth to Water	feet	75.00
Pump Efficiency	percent	0.50
Drive Efficiency	percent	0.90
Dryland Net Returns for Farm	dollars	17,870.00
Planned Years of Analysis	no.	25.00
Year Irrigation Ceased	no.	14.00
Present Value Over 14 Years:		
Net Returns	dollars	620,790.75
Returns to Water	dollars	382,345.00

Table 11. An Example of Model Printout Summarizing a Specified Scenario.

Item	Unit	Year 1	Year 14
Saturated Thickness	feet	70.17	11.97
Depth to Water	feet	79.83	138.03
Pumping Energy			
Natural Gas-Sprinkler Irrig.	mcf/af	12.65	15.21
Natural Gas-Furrow Irrig.	mcf/af	4.53	7.09
Electricity-Sprinkler Irrig.	kwh/af	607.24	730.06
Electricity-Furrow Irrig.	kwh/af	217.23	340.05
Well yield	gpm	370.02	105.44
Net Returns	dollars	49,985.36	32,396.14
Returns to Water	dollars	32,115.36	14,526.14
Total Acres Dryland	acre	106.67	211.91
Cotton	acre	0.0	0.0
Grain Sorghum	acre	106.67	211.91
Wheat, Grain Only	acre	0.0	0.0
Wheat, Grazing	acre	0.0	0.0
Total Acres Sprinkler Irrig.	acre	533.33	428.09
Corn	acre	0.0	0.0
Grain Sorghum	acre	533.33	428.09
Wheat, Grain Only	acre	0.0	0.0
Wheat, Grazing	acre	0.0	0.0
Total Acres Furrow Irrig	acre	0.0	0.0
Corn	acre	0.0	0.0
Cotton	acre	0.0	0.0
Grain Sorghum	acre	0.0	0.0
Soybeans	acre	0.0	0.0
Wheat, Grain Only	acre	0.0	0.0
Wheat, Grazing	acre	0.0	0.0
Light Feeders	hd.	0.0	0.0
Heavy Feeders	hd.	0.0	0.0
Marginal Value Product			
Period 1 Water	$/af	0.0	0.0
Period 2 Water	$/af	0.0	0.0
Period 3 Water	$/af	0.0	0.0
Period 4 Water	$/af	0.0	0.0
Period 5 Water	$/af	0.0	0.0
Period 6 Water	$/af	0.0	174.44
Period 7 Water	$/af	0.0	57.05
Period 8 Water	$/af	0.0	0.0
Period 9 Water	$/af	0.0	0.0
Period 10 Water	$/af	0.0	0.0
Sprinkler Irrigated Land	$/ac	73.66	0.0
Furrow Irrigated Land	$/ac	110.99	99.06
Total Land	$/ac	27.92	27.92

scenario being evaluated. Table 11 shows an example of results summarized in the model printout.

Fixed Costs

Using standard budgeting procedures, annual fixed costs were calculated for (1) machinery and equipment, (2) sprinkler and furrow distribution systems, (3) irrigation wells, and (4) pumping plants (Brown and Skinner 1977). Annual fixed costs are based on the expected life of the equipment. These fixed costs include depreciation, opportunity cost, and the allowance for taxes and insurance. Annual fixed costs for machinery and equipment are considered to vary with the level of irrigation. Therefore, three levels (low, intermediate, and high) of annual fixed costs were calculated for machinery and equipment on a per acre basis. Machinery and equipment fixed costs for the different crops, dryland and irrigated, were taken from the 1978 crop budgets developed by the area economists of the Texas Agricultural Extension Service (Extension Economists-Management).

Using the fixed cost figures for the respective dryland crops, a single estimate of fixed cost (a weighted-average) was derived for dryland production. This weighted-average estimate of fixed cost was weighted according to the number of dryland acres of each crop in the study area. In like fashion, a single-value estimate of machinery and equipment fixed cost for a high level of irrigation and an intermediate level of irrigation was calculated. The machinery and equipment fixed costs thus derived were $7.35 per acre for dryland production, $13.65 per acre for high levels of irrigation (a pre-plant plus two or more waterings), and $10.50 per acre for intermediate levels of irrigation (a pre-plant plus one or less waterings).

Annual fixed costs for sprinkler and furrow distribution systems were also established on a per acre basis. Total fixed cost for four center-pivot sprinkler systems, complete with installation, was estimated at $104,760 for 640 acres (Cantwell 1978). Out of each 160 acres, the center-pivot sprinkler irrigates a 133-acre circle, leaving 27 acres in the corners unirrigated. Annual fixed cost per acre for center-pivot sprinklers included a depreciation charge (assuming a useful life of 12 years), an opportunity cost (1.5 percent of average investment), and a charge for insurance (3 percent of new cost). Annual fixed cost for center-pivot sprinklers was estimated to be $31.97 per acre.

Total costs for a furrow irrigation system were calculated to be $59,130 for 640 acres (Shipley 1978). The estimate of annual fixed cost per acre for furrow irrigation also included a depreciation charge, an opportunity cost, and an insurance charge. Underground pipe and risers were depreciated over 15 years, while gated pipe and an assortment of irrigated pipe were depreciated over five years. The opportunity cost and the insurance charge were calculated in the same manner as for sprinkler irrigation. Annual fixed cost for the furrow systems was estimated to be \$11.90 per acre. The LP model included activities for the annual fixed cost of machinery and equipment and separate activities for annual fixed costs for sprinkler and furrow distribution systems.

Total annual fixed costs were estimated for (1) developed irrigation wells of various depths and (2) pumping plants (engines, pumps, and gearheads) appropriate for various well yields (gpm) and lifts (in feet). These costs for each water resource situation were arranged in matrix form and stored in the Fortran sub-programs, as shown in Tables 12 and 13.

For long-run analysis, fixed costs (along with variable costs) are subtracted from gross returns. The Fortran program selects appropriate fixed costs for irrigation wells, engines, pumps, and gearheads, depending upon the particular water resource situation of each year for each analysis: i.e., well yield and lift. As well yield and lift adjust, the associated well fixed cost adjusts. This means there is an implicit assumption that adjustments in the pumping plant occur and old equipment is sold for its depreciated or salvage value. The well fixed costs are subtracted from the LP estimated net returns to give estimated returns to the farm plan net of all variable and fixed costs.

Present Value of the Water Supply

The present value of the water supply is for a specific situation comprised of the present value of returns (annual

Table 12. Costs of Well Hole, Casing, Gravel Pack, Line Shaft, Column Pipe, Bearing and Gas Pipe. [a]

Depth (feet)	Total New Costs (dollars)	Annual Fixed Costs (dollars)
150	9198.50	863.35
200	11346.00	1074.38
250	13498.50	1285.38
300	15651.00	1496.39
400	19956.00	1918.42
500	24261.00	2340.44
600	28566.00	2762.46
700	34456.00	3324.67

[a] Based on information from Ed Finley, High Plains Irrigation Company 1978.

Table 13. Summary of Annual Fixed Costs for Engine,[a] Pump, and Gearhead.[b]

Well Yield (gpm)	Lift (feet)					
	75-100	101-150	151-200	201-300	301-400	401-500
	(dollars)					
0 - 150	394.25	480.94	575.94	681.63	803.94	1009.38
151 - 351	597.60	652.61	715.61	793.86	928.48	1195.00
351 - 600	639.56	694.78	793.86	985.46	1036.74	1490.77
601 - 800	655.29	720.15	803.48	1047.20	1088.99	1525.77

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[a] Based on information from Eddie Reasor, Buck Irrigation Company 1978.

[b] Based on information from Ed Finley, High Plains Drilling Company 1978.

income streams) attributable to the water over its economic life. In a traditional analysis, net returns to the farm plan are estimated and include both returns to land and to water. To estimate returns to water, it is necessary to subtract the present value of returns to dryland production (discounted returns to land). Returns to dryland production were estimated through applications of the model without any irrigation alternatives.

For analysis of the value of water, a 25-year limit was placed on each computer run due to computing cost limitations. This means that for many water resource situations there were several years of water supply remaining after the 25 years. The value of remaining water was needed to be included in the total present value of a given situation. Thus, a method for establishing the salvage value of remaining groundwater was required.

To determine the present salvage value of the water supply remaining at the end of 25 years, the 25-year limit was removed for selected recursive computer runs. These selected computer runs of the model for different quantities (saturated thickness) of water were made past year 25 to the point where all production reverts to dryland. The annual returns to the water used after year 25 were calculated and discounted to obtain the present salvage value of the water supply for 640 acres. By adding the present value of returns to the water used over 25 years, to the present salvage value of the water remaining after 25 years, the total present value of the groundwater supply was estimated.

The present value (salvage value) of the water supply remaining after 25 years was estimated with sprinkler, then separately with furrow irrigation for various levels of saturated thickness. For sprinkler irrigation a linear equation was fitted statistically to the data with present salvage value of water as a function of saturated thickness. An equation was first constructed with pump efficiency set at 50 percent, shown graphically in Figure 11. The equation is as follows:

$$PV_1 = -\$35250 + 1290.3782(ST) \qquad (14)$$

where

PV_1 = present salvage value of water remaining at the end of 25 years, with 50 percent pump efficiency and sprinkler irrigation;

ST = saturated thickness.

With center-pivot sprinklers and a 75 percent pump efficiency, computer runs were made for alternative levels of saturated thickness to estimate the present salvage value of groundwater remaining after 25 years. At each level of saturated thickness the present salvage value of water was increased due to pump efficiency being increased from 50 to 75 percent. The percent increase in present salvage value attributable to the higher efficiency was calculated, and a linear equation was constructed in which the percent increase in present salvage value was a function of saturated

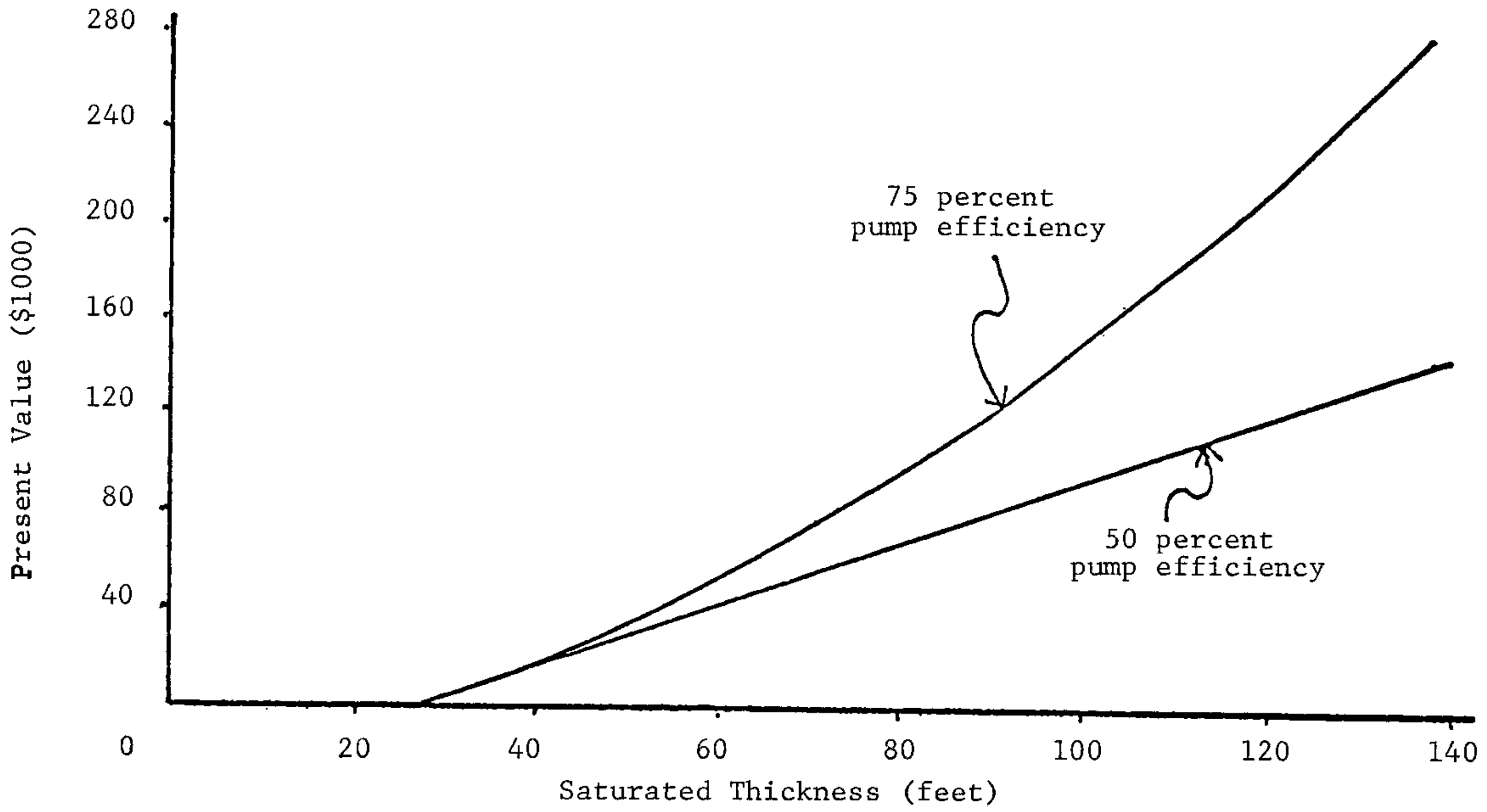

Figure 11. Present value of the groundwater remaining after 25 years, for a center-pivot sprinkler irrigation system on 640 acres, a typical farm: Texas High Plains.

thickness. This equation was used as an adjustment factor to modify equation (13) in order to formulate equation (14) which estimates the present salvage value of groundwater after 25 years with 75 percent pump efficiency and center-pivot sprinklers. This equation is as follows:

$$PV_2 = -\$35250 + 1290.3782(ST) + [(-.326463 + .009081ST)(-35250 + 1290.3782ST)] \quad (14)$$

where

PV_2 = present salvage value of water remaining at the end of 25 years, with 75 percent pump efficiency and sprinkler irrigation;

ST = saturated thickness;

$-.326463 + .009081\ (ST)$ = adjustment factor.

This equation reduces to the following:

$$PV_2 = -\$23742.0385 + 549.0041(ST) + 11.7179(ST)^2 \quad (15)$$

Equation (15) is shown graphically in Figure 11.

In like fashion, equations were formulated to estimate the present salvage value of water under furrow irrigation, first with 50 percent pump efficiency, then with 75 percent pump efficiency. These equations (shown graphically in Figure 12) are:

$$PV_3 = -\$50061 + 653.6703(ST) \quad (16)$$

where

PV_3 = present salvage value of water remaining at the end of 25 years, with 50 percent pump efficiency and furrow irrigation;

ST = saturated thickness;

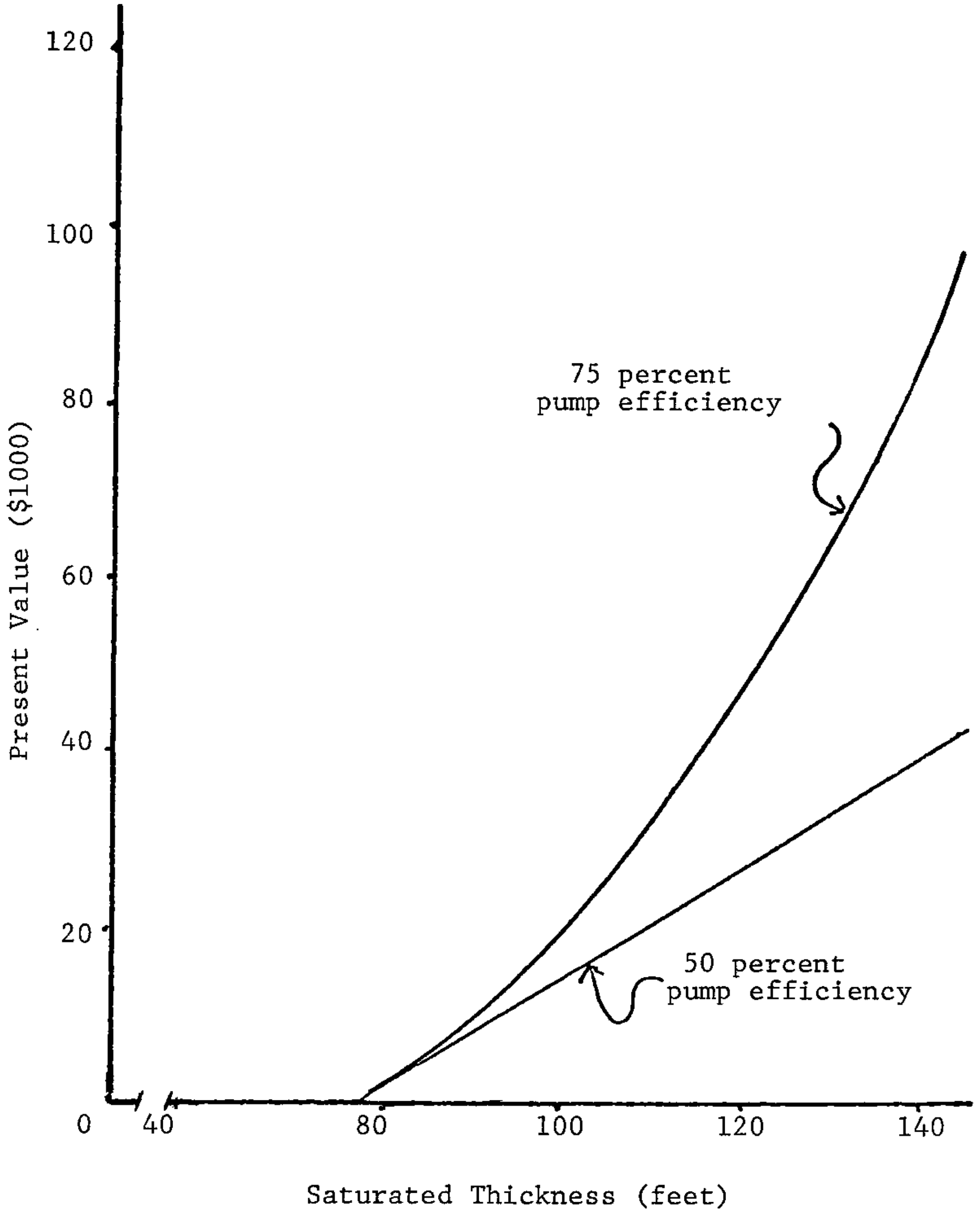

Figure 12. Present value of the groundwater remaining after 25 years, for a furrow irrigation system on 640 acres, a typical farm: Texas High Plains.

and

$$PV_4 = -\$50061 + 653.6708(ST) + [(-195.8649 + 2.255ST)(-50061 + 653.6708ST)] \qquad (17)$$

where

PV_4 = present salvage value of water remaining at the end of 25 years, with 75 percent pump efficiency and furrow irrigation;

ST = saturated thickness.

Equation (17) reduces to the following:

$$PV_4 = \$47990 - 1755.516(ST) + 14.740(ST)^2 \qquad (18)$$

These equations are used to estimate salvage value of groundwater remaining after 25 years. By adding the salvage value of groundwater remaining after 25 years of analysis, total present value of the groundwater supply is estimated. Again, a 25-year limit on the analysis for all scenarios considered was necessary due to budget limitations on computer costs.

Discount Rate

To estimate a present value for a quantity of groundwater, future returns are discounted. For this analysis a discount rate of 7.3 percent adjusted for an inflation rate of 5.8 percent was used (Reneau, et. al. 1978). Effectively this means a real discount rate of 1.5 percent was used. Again, this rate is an approximation of the difference between the prime rate and the rate of inflation; it represents a time preference rate for money. The discount rate in this case is exclusive of an inflation rate because it is assumed that either all prices (for commodities and purchased inputs) hold constant over time or all prices inflate at the same rate.

The above discount rate does not consider risk and uncertainty in the discounting of future returns. An alternative discount rate of 6 percent was used. This discount rate included a 4.5 percent allowance for risk (not a measure of risk) and uncertainty associated with future returns. A distinction has been made between risk and uncertainty (Heady 1952). With risk, there is a known variability in incomes, and probabilities can be assigned to each level of income. With uncertainty, the probabilities of income levels cannot be assigned to the various income levels because they are not known. The use of discount rates which include an allowance for risk and uncertainty is based upon the concept that investors demand higher returns for more risky projects (Martin, Petty, Keown, and Scott 1979).

Method of Analysis

The model was developed to investigate several issues, including increasing real input prices, tenure, crop price sensitivity, effect of pumping efficiency, effect of new technology, and credit implications. Basically, the analysis of these factors included the three water resource situations (Table 4) and the furrow and center-pivot sprinkler systems. Model adjustments for each of these evaluations are discussed below.

Effects of Rising Natural Gas Prices

Static and temporal analyses were conducted to estimate the effects of rising natural gas prices. For the static analysis, annual model applications were made using three different price levels of natural gas: $1.50, $2.00, and $2.50 per one-thousand cubic feet (mcf). The $1.50 per mcf natural gas price was approximately the prevailing price at the beginning of this study (1978). Price increases to $2.00 and $2.50 per mcf were considered sufficient to cover any actual natural gas price increase in the short-run. This phase of the analysis was primarily to estimate short-run effects of the increased levels of natural gas prices (from $1.50 to $2.00 and to $2.50 per mcf) upon (1) net returns to the farm plan, (2) natural gas usage, and (3) cropping patterns for the typical farm.

Estimating the effects of rising natural gas prices through time was achieved through recursive applications of the model. The analysis was done (1) with the price of natural gas held constant over time at $1.50 per mcf, (2) with the price of natural gas set initially at $1.50 per mcf and increased $0.10 per mcf per year, and (3) with the price of natural gas set initially at $1.50 per mcf and increased $0.25 per mcf per year. The results based on a constant natural gas price of $1.50 per mcf served as a basis for comparison.

Effects of a Typical Rental Arrangement

The customary share-cropping arrangements for the area include a share-renter farmer paying to the landlord one-third of grain (corn, grain sorghum, and wheat) and wheat pasture, and one-fourth of cotton produced. In addition, the landlord pays a share of the costs of fertilizer, harvesting, hauling, drying, and ginning. Of these costs he pays the same share(s) as he receives from the sale of crops (one-fourth for cotton and one-third for all other crops). Coefficients in the corresponding sell activities and transfer rows were changed to reflect the renter's decreased share of the crops. Likewise, coefficients in certain purchase activities and transfer rows were modified to reflect the renter's decreased share of the cost of fertilizer, harvesting, hauling, drying for corn, and ginning cotton. Evaluation of this rental arrangement was made on an annual and temporal basis.

The temporal analysis also included consideration of the effect of the price of natural gas being held constant at \$1.50 per mcf as well as increasing \$0.10 per mcf per annum. The outcomes of these runs, with corresponding owner-operator analyses, permits estimation of the effects of the rental arrangement on such issues as net returns and economic life of the water supply.

Price Sensitivity Analysis

Crop price sensitivity analysis was accomplished by means of annual applications of the model (static analysis). Model applications were under three different crop price scenarios. Base computer runs were made with target crop prices which constituted the first crop price scenario. The computer runs were repeated but with cotton and soybean prices reduced by 20 percent while other crop prices remained at target levels (scenario two). A last evaluation was based on grain and soybean price increase at 20 percent, with the other crop prices held at target levels (scenario three). Since cotton is often included in farm plans (to the south of the Candian river), crop price scenarios (2 and 3) were used in which the relative price of cotton was reduced. This was done to see if these price changes would force cotton out of the farm plan.

Price sensitivity analysis also included simultaneous, one-step increases in the prices of energy related inputs as follows: (1) natural gas price increased from $1.50 to $2.50 per mcf, (2) nitrogen price from $0.16 to $0.25 per pound, (3) gasoline price from $0.50 to $0.80 per gallon, and (4) diesel price from $0.50 to $0.80 per gallon.

Effects of Improved Pump Efficiency

The effects of improved pump efficiency were estimated for both the furrow and the center-pivot sprinkler systems within the Poor and Good water resource situations. The initial computer runs were with a pump efficiency of 50 percent. These were the base runs (standards of comparison). The model was then run with pump efficiency increased from 50 percent to 75 percent. Comparisons of these computer runs to the base runs provided estimates of the effects of the improved pump efficiency on the present value and economic life of the groundwater supply. In addition, improvement in the net present value of the water supply provides an upper limit on the costs that could be justified to achieve the improved pump efficiency.

Effects of Improved Technology

Improved technology for this study is defined as any change in production methods which requires less inputs (decreased levels of use) to maintain a given level of output or increases production with the same level of inputs. The analysis of improved technology was temporal, and the principal issues involved (1) improved water-use efficiency, (2) reduced irrigation fuel requirements, and (3) changing labor requirements. Yields were not adjusted in any of the analyses. A series of recursive model applications were made for both Poor and Good water. The model was initially applied for a center-pivot sprinkler system for each of the following assumptions:

(1) 90 pounds of pressure per square inch (psi),

with no water savings[8] (a base run for comparisons).

(2) 10 pounds of pressure per square inch, with no water savings.

(3) 10 psi with 25 percent less water required.

(4) 10 psi with 50 percent less water required.

For furrow irrigation, the model was applied recursively to both Poor and Good water situations. Within these water resource situations recursive computer runs were made under the following assumptions:

(1) no labor constraints, no water savings (base run).

(2) 25 percent less water required, irrigation labor requirements doubled, and no labor constraints.

Current equipment was considered as adequate, hence, fixed costs remained unchanged. The basis for increasing labor requirements with a 25 percent decrease in water use results from reduced length of crop rows so that water could be applied more uniformly and with less evaporation, runoff, and percolation. But with shorter rows, more irrigation labor would be needed. Irrigation was assumed to double to achieve the 25 percent decrease in water use.

Effects of Credit Constraints

Credit constraints were analyzed in the short-run

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[8] With no water savings, water requirements are as originally established for the center-pivot sprinklers.

(static analysis). The applications of the model were for one year and fixed costs were excluded from consideration. Base runs were made (without credit constraints) for both sprinkler and furrow systems under Poor and Good water. These runs were repeated but with credit constraints imposed for each of the two-month borrowing periods. These constraints were imposed by bounding the borrowing activities.

The bounding procedure limits the borrowing that takes place within each credit period. As the model progresses from the first credit period to the sixth credit period, an increased level of borrowing is allowed. If the credit limit is not used in a given credit period, the unused credit can be carried over to the next credit period. Hence, there is a control on the outstanding loan balance throughout the year. The reason for credit constraints by periods is to simulate a creditor's control of the outstanding loan balance. A creditor, such as a bank or some other financial institution, will typically approve a total loan limit for a farm operator that is considered to be adequate for a production year. These funds are then disbursed throughout the course of that year. The proper supervision of a given loan includes monitoring that loan to insure that the approved loan funds last through the production year (Potts 1978).

To evaluate the effect(s) of total credit limits, an accounting row was included in the model to accumulate the total dollars borrowed for operating expenses. The right-hand side constraint was initially set at $150,000, a value considered to be non-constraining (Potts 1979). This limit was reduced in $5,000 increments to estimate the effects of a constraint on total credit.

Estimation was also made of the cost to a farmer of credit reserves. The parametric reductions (of $5,000) in borrowing were treated as self-imposed by the farmer. The decreases in annual net returns represented the costs of increased credit reserves.

CHAPTER V

ENERGY AND CROP PRICE IMPACTS

This chapter reports the expected effects of different prices of natural gas and other energy-related inputs as well as crop prices on a typical 640 acre farm in the Texas High Plains for selected alternative scenarios. The analysis was separated into short-run impacts and long-run impacts.[9] For the short-run, the analysis was for one single year, and only variable costs were included.

The long-run analysis included all costs (fixed and variable) and a planning horizon of at least 25 years or to economic exhaustion of the water supply, whichever occurred first. Net return streams over the planning horizon were discounted to estimate the present value of returns and thus provides a basis for comparison.

The study considered implications for the owner-operator as well as the renter-operator. For other energy-related inputs, two price scenarios were specified for analysis. Lastly, three crop price scenarios were developed to analyze sensitivity of farm plans to product price adjustments. The results of analyses with furrow irrigation apply only to that part of the study area to the south of the Canadian

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[9] The analyses herein referred to as long-run analyses are technically short-run analyses because some of the resources, such as land and labor, were fixed in quantity.

River. This is because cotton is included as a crop option with furrow irrigation, and cotton is not grown to the north of the river. In addition, results with the Poor water situation apply only to the south of the river.

Natural Gas Price Impact

Natural gas prices were evaluated as to their effects upon typical farms of the Texas High Plains. The analysis was directed to an owner-operator and then expanded to review the effect for alternative arrangements. The analysis considered alternative water resource situations and irrigation distribution systems.

Static Analysis

Following are the results of a static analysis of increased natural gas prices, first, upon an owner-operator and, secondly, upon a renter-operator.

Owner-Operator

For the static or single-year analysis of the owner-operator, natural gas prices of \$1.50, \$2.00, and \$2.50 per mcf were used. The annual net returns (returns above variable costs) with the specified natural gas prices for the respective water resource situations and irrigation systems are presented in Table 14. In the short-run (one year), annual net returns for Fair water (125 feet saturated thickness and 175 feet of lift) were approximately 5 to 8 percent

Table 14. Annual Returns Above Variable Costs for Selected Natural Gas Prices for 640 Acres, a Typical Farm: Texas High Plains.

Water Resource Situation[a]	Price of Natural Gas ($/mcf) 1.50	2.00	2.50
Poor			
Sprinkler	90,129	85,982	81,835
Furrow	71,910	70,114	68,330
Fair			
Sprinkler	85,520	79.907	74,294
Furrow	66,152	62,712	59,489
Good			
Sprinkler	82,063	75,350	69,453
Furrow	62,059	57,919	54,411

[a] Poor water has a saturated thickness of 75 feet and a lift of 75 feet, Fair water has a saturated thickness of 125 feet and a lift of 175 feet, and Good water has a saturated thickness of 250 feet and a lift of 250 feet.

below those of Poor water, while Good water (250 feet saturated thickness and 250 feet of lift) returns were 9 to 14 percent less. When the price of natural gas was increased to $2.50 per mcf, the difference in annual net returns associated with the Poor water and Good water resource situations was even more pronounced, e.g., net returns estimated with the Good water resource situation were 17.5 percent below returns with Poor water. The greater net returns with Poor water were due primarily to the reduced lift.

Increasing the price of natural gas had its greatest effect upon annual net returns with Good water. When the price of natural gas was increased from $1.50 to $2.00 per mcf, annual net returns with Good water were reduced $6,713 (8.2 percent) with sprinkler irrigation and $4,140 (6.7 percent) for furrow systems. With Fair water, annual net returns decreased $5,613 (6.6 percent) for sprinkler and $3,440 (5.2 percent) for furrow irrigation.

An increase in the price of natural gas from $1.50 to $2.50 per mcf did not affect the use of natural gas in Poor water. In the Good water situation, natural gas used dropped approximately 20 percent for both sprinkler and furrow irrigation. The static analysis suggests that in the short-run with a natural gas price of $1.50 per mcf or higher, the reduced lift of a small groundwater supply outweighs the benefits of a large deep groundwater supply on a current year basis, but not necessarily over time.

Owner and Renter Comparison

Tenure arrangements were evaluated in conjunction with natural gas prices. Results of the analysis have implications regarding cropping patterns, levels of irrigation, demand for natural gas, economic life of the water supply, profitability for the operator and landlord, the ability of producer to survive economically, and incentives for alternatives of tenure arrangements.

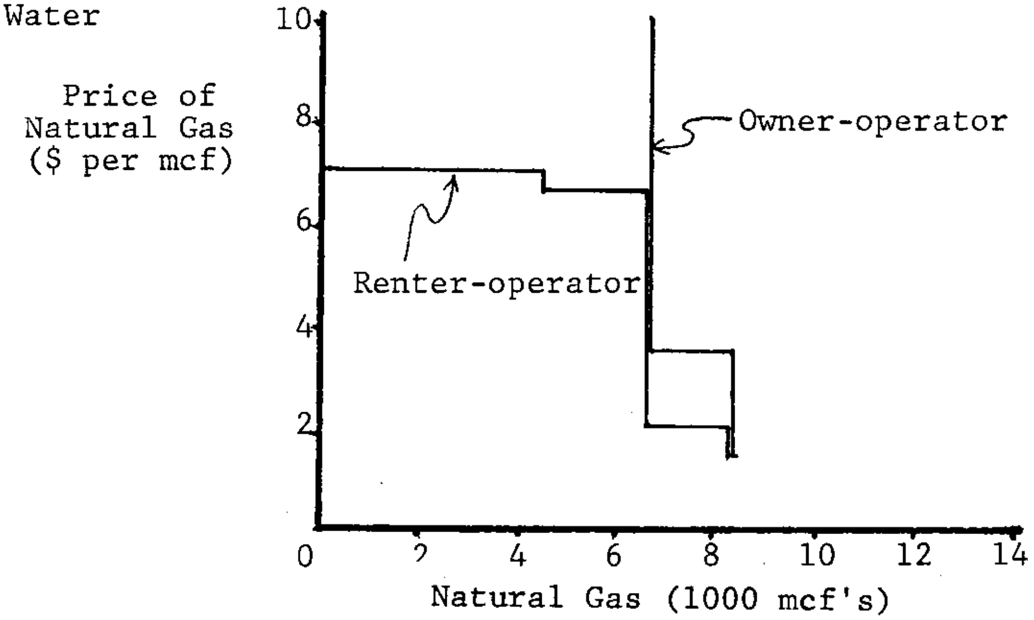
The static analysis is based on customary rental arrangements for the Texas High Plains which are described in Chapter IV. The following discussion compares short-run adjustments to rising gas prices made by an owner-operator with those made by a renter-operator. To estimate the impact of rising natural gas prices, the gas price was increased parametrically from $1.50 to $10.00 per mcf. Comparisons were first made when the operators used sprinkler irrigation and then when they used furrow irrigation. The estimated returns for both owner-operator and renter were returns above variable costs.

Sprinkler Irrigation. With sprinkler irrigation and a Poor water resource situation, the cropping pattern for both owner-operator and renter-operator consisted of 640 acres of grain sorghum (106.7 dryland and 533.3 irrigated). The irrigated grain sorghum received 1 pre-plant and 4 post-plant irrigations. As the price of gas was increased, the levels of irrigation were reduced, with the renter-operator decreasing irrigation levels at lower gas prices than did the owner-operator. At a gas price of $3.60 through $10.00 per mcf, the owner-operator reduced his irrigation level to 1 preplant plus 3 post-plant waterings. The renter reduced irrigation by 1 and 2 waterings at gas prices of $2.10 and $6.67 per mcf, respectively. At a gas price of $7.05 per mcf, irrigation was no longer economically feasible for the renter-operator, and all acres reverted to dryland grain sorghum. Cropping patterns that occurred as the gas price was increased are shown in Table 31, Appendix D.

Due to the increased lift in the Good water resource situation and the resulting increase in natural gas requirements, rising gas prices had a more pronounced impact than in Poor water. At a gas price of $1.50 per mcf, the cropping pattern was the same as in Poor water. Changes in the cropping pattern are shown in Table 32, Appendix D. The owner-operator reduced post-plant irrigations from 4 to 3 and then to 2 as the price of gas increased to $4.20 and $6.42 per mcf, respectively. All acres shifted to dryland at a gas price of $7.09 per mcf. The renter reduced post-plant irrigations from 3 to 2 at a gas price of $4.09, and then terminated irrigation when the price of natural gas rose to $4.33 per mcf.

Increased natural gas prices reduced profits attributable to irrigation, resulting in a decline in the quantities of natural gas demanded. Short-run derived demand for natural gas (shown in Figure 13) is inelastic over a price

(a) Poor Water



(b) Good Water

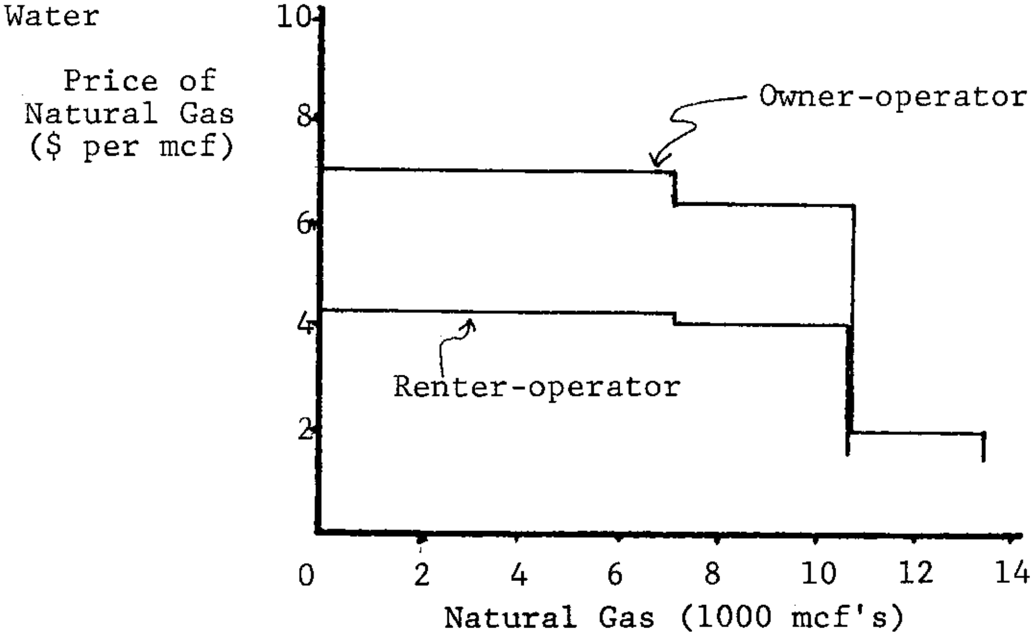


Figure 13. Short-run derived demand for natural gas with sprinkler irrigation for 640 acres, a typical farm: Texas High Plains.

range of $1.50 to $10.00 per mcf for an onwer-operator in a Poor water resource situation. A price increase of 140 percent (from $1.50 to $3.60 per mcf) resulted in a 20 percent decline in quantity of natural gas demanded and an increase in pumping costs of 92 percent. From a gas price of $3.60 to $10.00 per mcf, the demand is perfectly inelastic. By comparison, the renter-operator is more responsive to increased gas prices, but even so, demand is inelastic. A 40 percent increase in the gas price (from $1.50 to $2.10 per mcf) led to a 20 percent decline in gas used and a 12 percent increase in pumping costs. When the gas price reached $6.67 per mcf, the renter decreased gas use by 33 percent, and when the gas price was increased to $7.05 per mcf, gas use was terminated.

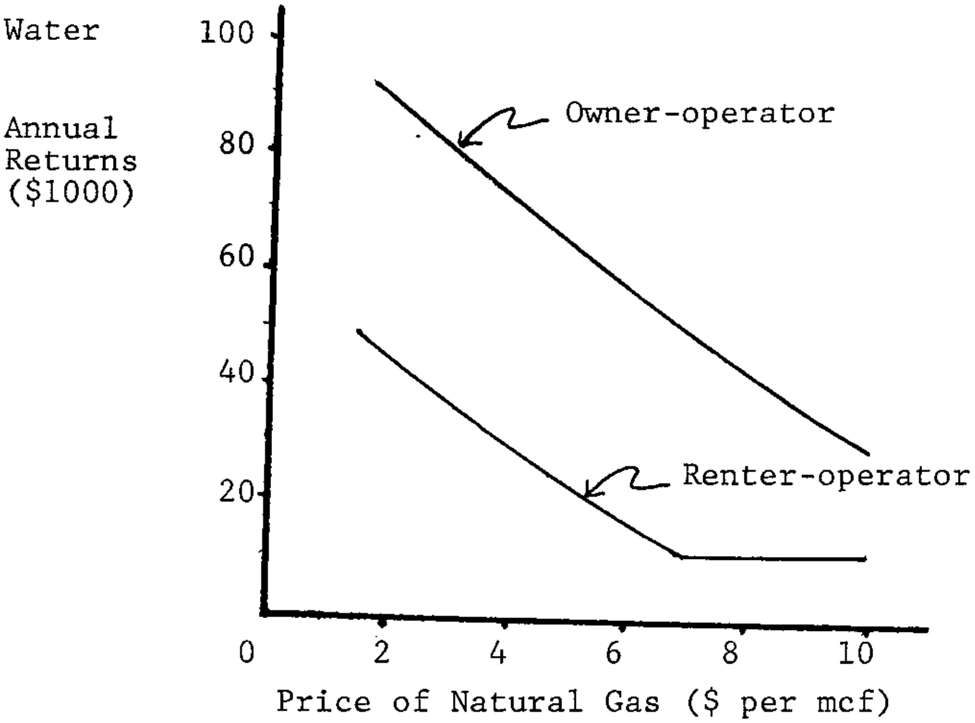
Due to the greater fuel requirements, demand for natural gas in Good water is relatively more elastic than in Poor water. For the owner-operator, a gas price increase of 47 percent (from $1.50 to $2.20 per mcf) resulted in a 20 percent decline in gas purchased. Demand for gas was inelastic within a price range of $2.20 to $6.42 per mcf. At $6.42 per mcf, gas use fell by 33 percent and then to zero when the gas price was increased to $7.09. The renter purchased 20 percent less gas with a gas price of $1.50 per mcf than the owner-operator. The renter's demand was inelastic up to $4.09 per mcf, but at that point gas purchased dropped 33 percent. At a gas price of $4.33, irrigation was no longer profitable, and the renter ceased to purchase natural gas.

Annual net returns (using center-pivot sprinklers) declined rapidly with rising gas prices, as shown in Figure 14. In Poor water when the gas price was increased from $1.50 to $10.00 per mcf, the owner-operator's annual net returns (returns above variable costs) decreased from $90,129 to $30,244. On the average, net returns for the owner-operator decreased $7,000 per $1.00 increased in natural gas price. The renter's net returns decreased from $48,448 to $11,456 for a natural gas price increase from $1.50 to $7.05 per mcf. The renter's net returns declined $6,700 per $1.00 increase in gas price, slightly less than the owner-operator's, perhaps due to his irrigating at lower levels and less irrigation cost.

Increased natural gas prices have an even greater impact on annual net returns in the Good water resource situation. Returns for the owner-operator declined from $82,063 to $22,574 for a natural gas price increase from $1.50 to $7.09 per mcf. Returns for the renter were reduced from $41,000 to $11,456 when the gas price rose from $1.50 to $4.33 per mcf. Returns for both owner-operator and renter declined approximately $10,200 per $1.00 increase in the price of natural gas under the Good water resource situation.

Furrow Irrigation. Cotton was included in a model as a crop option with furrow irrigation. The results obtained are applicable only for that part of the study area to the south of the Canadian River. Rising natural gas prices were

(a) Poor Water



(b) Good Water

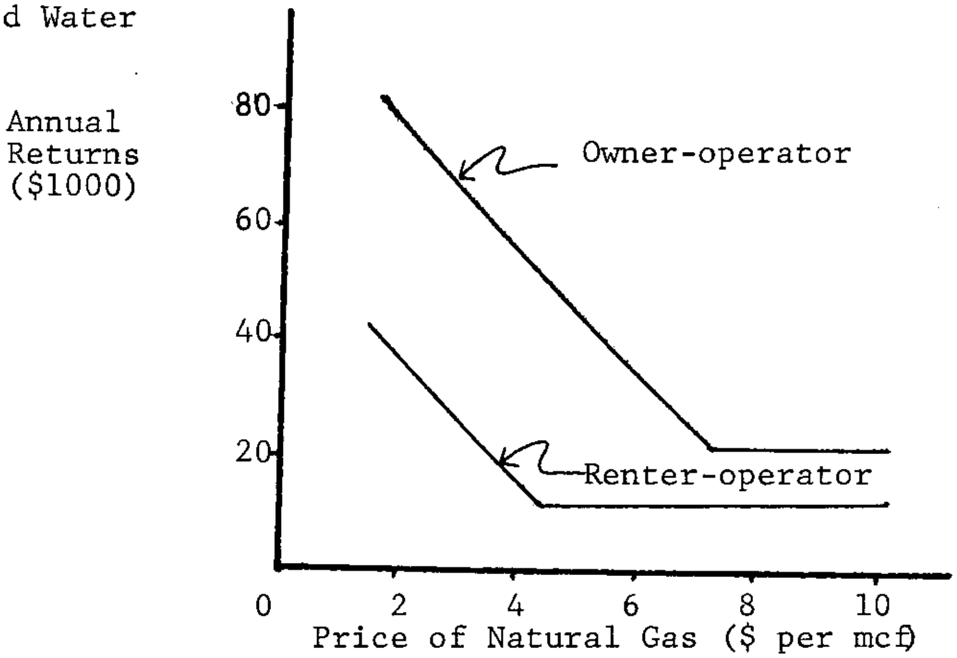


Figure 14. Annual returns above variable costs to land, water, management, and risk with center-pivot sprinklers for 640 acres, a typical farm: Texas High Plains.

estimated to affect cropping patterns more under a furrow irrigation system than with a sprinkler irrigation system. Estimated cropping patterns resulting from increased gas prices are presented in Tables 31 and 32, Appendix D. In the Poor water situation with a natural gas price of $1.50 per mcf, the owner-operator's crops consisted of dryland wheat (80.7 acres), irrigated cotton (427.7 acres), and wheat with grazing (109.8 acres). A gas price of $2.28 per mcf caused a shift of 30.8 additional acres to dryland wheat production. At a gas price of $6.86 per mcf, the cropping pattern for an owner-operator included dryland grain sorghum (13.5 acres), dryland wheat with grazing (168.1 acres), and irrigated cotton (458.4 acres). Irrigation of the cotton was reduced by one watering, to 1 pre-plant plus 2 post-plant waterings. Further natural gas price increases to $10.00 per mcf resulted in no additional adjustments in cropping pattern or irrigation levels.

Cropping patterns for the renter-operator, with increasing natural gas prices, are shown in Tables 31 and 32, Appendix D. For the renter-operator in the Poor water resource situation, a gas price of $1.50 per mcf resulted in a cropping pattern of dryland grain sorghum (10.9 acres), dryland wheat with grazing (157.4 acres), irrigated cotton (458.1 acres), and irrigated wheat with grazing (3.5 acres). Dryland acres for the renter were initially more than double those of the owner-operator. However, no major shifts in crops occurred until the price of natural gas was increased to $8.36 per mcf. At that point, 69.1 additional acres reverted to dryland production. Grain sorghum was then produced on all the acres where no irrigation water was used. The level of irrigation for remaining cotton was reduced by one watering, to 1 pre-plant and 2 post-plant waterings.

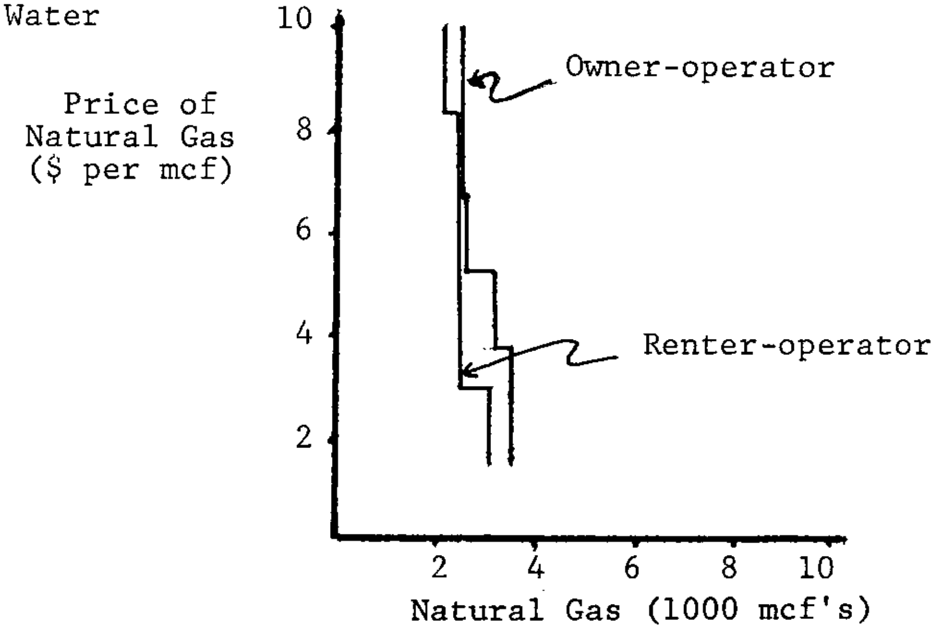
The impact of higher gas prices upon cropping patterns is much greater with increased lift, as in the Good water situation. With Good water and a gas price of $1.50 per mcf, the owner-operator's estimated cropping pattern included 171.7 acres of dryland wheat with grazing. Irrigated crops were cotton (455.3 acres), grain sorghum (3.4 acres), and wheat with grazing (9.6 acres). At a gas price of $2.34 per mcf, irrigated wheat was eliminated, and cotton irrigation was reduced by one watering, to 1 pre-plant plus 2 post-plant waterings. With a $4.99 per mcf natural gas price, 40 additional acres shifted to dryland production. At the same time the dryland crop mix changed from 13.5 acres to 127.5 and from 168.1 to 94.1 for grain sorghum and wheat with grazing, respectively. A gas price of $6.57 per mcf brought an increase in dryland grain sorghum to 250.8 acres and a decrease in irrigated cotton to 389.3 acres. Irrigation of these cotton acres was reduced an additional watering to 1 pre-plant and 1 post-plant watering. Finally, all acres shifted to dryland production when the price for natural gas was increased to $7.83 per mcf.

In Good water, crops were adjusted by the renter-operator in response to a higher natural gas price pattern similar to the owner-operator, but at a lower price in each case. With a gas price of $2.94 per mcf, the cropping pattern consisted of 250.8 acres of dryland grain sorghum and 389.3 acres of irrigated cotton, which is the same as for the owner-operator when the gas price was $6.57 per mcf. The renter terminated irrigation when the gas price reached $4.56 per mcf, compared to $7.83 per mcf for the owner-operator.

An estimate of short-run derived-demand for natural gas by a typical 640 acre farm with furrow irrigation, is shown in Figure 15. Demand for natural gas is less under furrow irrigation than under sprinkler irrigation, as shown by comparing Figures 13 and 15.

For the Poor water situation, the owner-operator's estimated demand for natural gas was inelastic. A 52 percent gas price increase (from $1.50 to $2.28 per mcf) resulted in less than a 2 percent decrease in gas purchased, while increasing variable pumping costs 49 percent. A gas price increase from $3.09 to $3.73 per mcf (20.7 percent increase) decreased gas purchased by 9.7 percent. The greatest adjustment in the quantity of gas purchased occurred as the price of natural gas was increased from $3.73 to $5.22 per mcf. Gas purchased fell 21 percent, while variable pumping costs rose 9.1 percent. From $5.22 to $10.00 per mcf, demand was perfectly inelastic. With a gas price of $1.50 per mcf, the renter-operator purchased 12.3 percent less gas than the owner-operator. As the natural gas price was increased to $10.00 per mcf, the renter made only 2 adjustments in the

(a) Poor Water



(b) Good Water

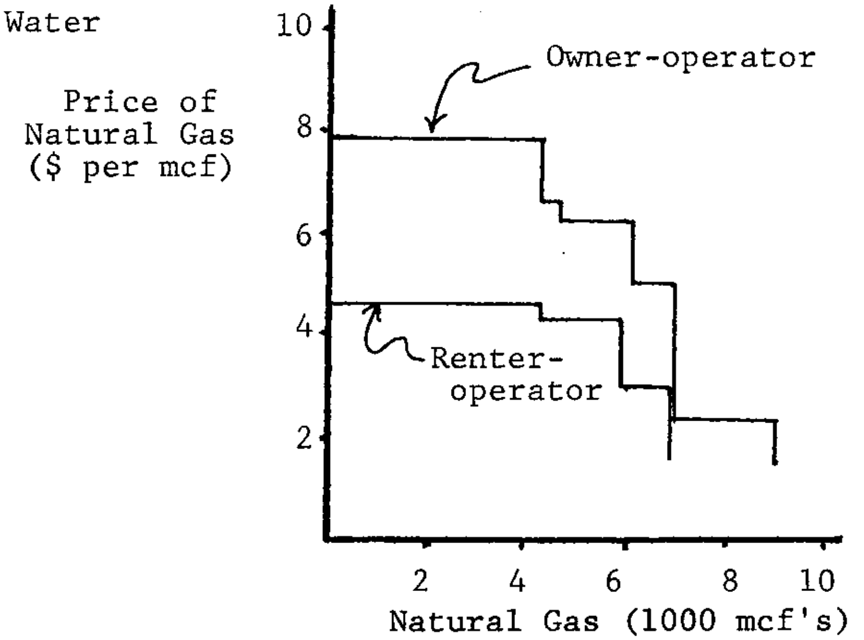


Figure 15. Short-run derived demand for natural gas with furrow irrigation for 640 acres, a typical farm: Texas High Plains.

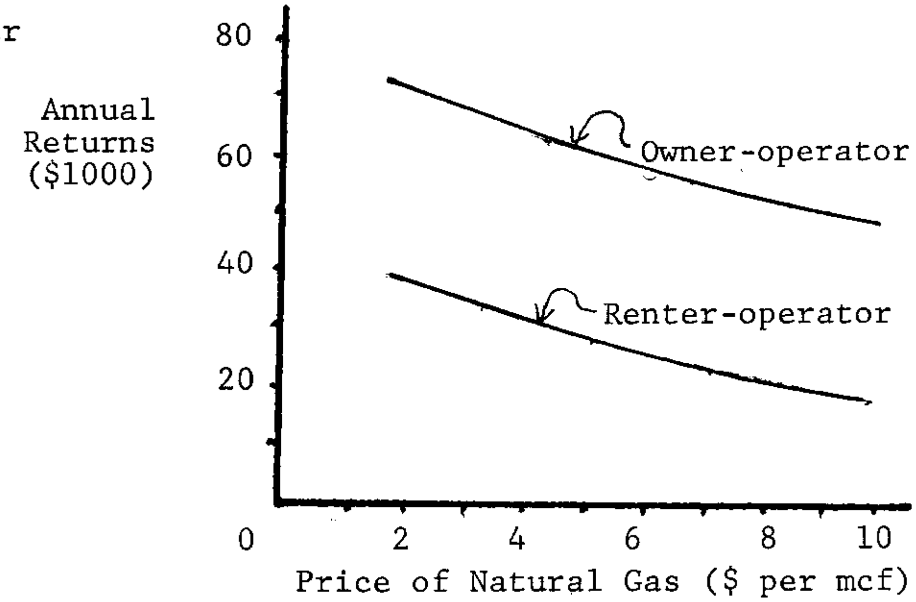
quantity of gas purchased, i.e., a gas price of $2.95 and $8.36 per mcf, gas purchased declined 21.6 percent and 15.1 percent, respectively. At the same time, variable pumping costs increased 54.4 percent and 104.5 percent.

For a Good water situation, a rising natural gas price was estimated to have a much greater effect upon an irrigation farmer's demand for the gas than in Poor water. Demand in Good water is much more elastic. When the gas price is increased from $1.50 to $2.34 per mcf (56 percent increase), the owner-operator is estimated to reduce gas purchased by 21.9 percent with an associated increase in variable pumping costs of 21.9 percent. Further decreases in natural gas purchased occurred at $4.99 per mcf (8.7 percent decrease), $6.20 per mcf (26.7 percent decrease), and $6.57 per mcf (7 percent decrease). At a gas price of $7.83 per mcf, gas purchases fell to zero.

The renter-operator in a Good water situation decreased gas used 15.1 percent at a gas price of $2.94 per mcf and another 26.7 percent at $4.31 per mcf. The renter ceased to purchase gas and to irrigate when the gas price rose to $4.56 per mcf. Adjustments by the renter in gas used were quite similar to the owner-operator's, but 2 of these 3 adjustments occurred at substantially lower prices than for the owner-operator.

Figure 16 shows the estimated relationship between natural gas price and returns above variable costs for a 640 acre farm under furrow irrigation. In the Poor water situation,

(a) Poor Water



(b) Good Water

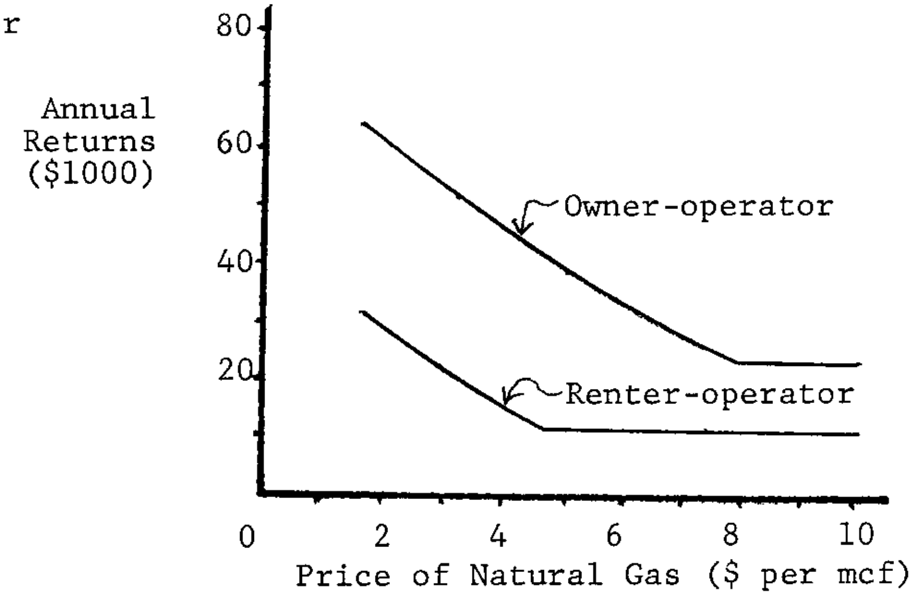


Figure 16. Annual returns above variable costs to land, water, management, and risk with furrow irrigation for 640 acres, a typical farm: Texas High Plains.

annual returns above variable costs for the owner-operator were $71,910 with a gas price of $1.50 per mcf and declined to $47,314 when the gas price was increased to $10.00 per mcf. Annual returns above variable costs for the renter-operator were reduced from $38,478 to $17,117 when the gas price was increased from $1.50 to $10.00 per mcf. For each $1.00 per mcf increase in natural gas prices, returns decreased $2,890 and $2,513 for the owner-operator and renter, respectively.

In a Good water situation, annual returns above variable costs for an owner-operator were estimated to decrease from $62,059 to $22,574 as the gas price rose from $1.50 to $7.83 per mcf. Returns to renter declined from $30,483 to $11,456 as the gas price increased from $1.50 to $4.56 per mcf. Returns for owner-operator and renter, were reduced approximately $6,200 per $1.00 increase in the price per mcf of natural gas.

To summarize, the implications of the static analysis on effect of rising natural gas price upon returns above variable costs provide initial insight. Annual returns above variable costs were most affected by increased natural gas prices in a Good water situation with sprinkler irrigation. These returns for an owner-operator and a renter were estimated to decrease approximately $10,200 for each $1.00 per mcf increase in the price of natural gas. The annual returns were affected least in a Poor water situation, with furrow irrigation, i.e., an estimated decline of only $2,600 for each $1.00 per mcf increase in gas price.

While the decline in annual returns above variable costs due to increased natural gas prices are very significant, the absolute levels of these annual returns are also of great importance. The returns are much lower for the renter than for the owner-operator in all cases (see Figures 14 and 16). This places the renter in a position more precarious than that of the owner-operator. Even though annual returns above variable costs are positive, only a minimum amount is available for fixed costs, living expenses, and to service debts for the owner-operator and renter. With a rising natural gas price, an operator's returns above variable costs are reduced and the viability of the farm threatened. In the case of the renter, it is likely that alternative rental arrangements will evolve that include a sharing of irrigation costs by the land owner. For the owner-operator it means a reduction in returns to his land and water investment and may have severe implications for many area producers.

Temporal Analysis

While increased natural gas prices have a significant short-run effect upon typical farms on the Texas High Plains, the temporal (long-run) effects of rising natural gas prices are even more pronounced. Variable pumping costs are increased, not only due to rising gas prices, but also due to increased irrigation fuel requirements as the water table declines. The following is an evaluation of the temporal effects of rising natural gas prices, first, for an owner-operator and, then, for a renter-operator.

Owner-Operator

Implications of the temporal effects of an increasing natural gas price for an owner-operator are shown in Table 15. As expected, an increasing natural gas price decreased the present value of the groundwater supply, with the most pronounced reduction occurring with a Good water situation and sprinkler irrigation. This is due to the greater lift associated with deeper water. The estimated present value of the groundwater supply declined 60.8 percent and 83.7 percent, with Good water and a sprinkler system, when the price of gas was increased annually $0.10 and $0.25 per mcf as compared to a constant $1.50 per mcf gas price. Similarly, with Poor water the estimated present value of the groundwater supply declined 18.4 percent and 45.6 percent.

The reduction in the present value of groundwater was noticeably less with furrow irrigation than with sprinkler irrigation, due to reduced water pressure in the distribution system. With furrow irrigation, the present value of groundwater was reduced 60.3 percent and 78.9 percent with Good water and 10.3 percent and 22.8 percent with Poor water, given an annual natural gas price increase of $0.10 and $0.25 per mcf annually compared to the $1.50 per mcf price.

With Poor water, irrigation was continued for 12 to 14 years, regardless of the price of natural gas or the

Table 15. Expected Effect of a Rising Natural Gas Price for 640 Acres, a Typical Farm: Texas High Plains.

Item	Unit	Water Resource Situation[a]		
		Poor	Fair	Good
Present Value of Groundwater				
Sprinkler				
$1.50/mcf gas price	$1000	370.8	490.5	607.0[c]
$0.10/mcf annual rise	$1000	302.8	260.5	237.8
$0.25/mcf annual rise	$1000	201.9	133.2	99.0
Furrow				
$1.50/mcf gas price	$1000	249.0	306.7	348.1[c]
$0.10/mcf annual rise	$1000	223.3	192.5	138.3
$0.25/mcf annual rise	$1000	192.2	112.2	73.3
Years of Irrigation and Ending Saturated Thickness[b]				
Sprinkler				
$1.50/mcf gas price	year(feet)	14(12)	25(19.6)	25(129.2)
$0.10/mcf annual rise	year(feet)	14(12)	20(39)	17(178.5)
$0.25/mcf annual rise	year(feet)	14(12)	10(82.5)	8(216.2)
Furrow				
$1.50/mcf gas price	year(feet)	12(12)	24(10)	25(132.6)
$0.10/mcf annual rise	year(feet)	12(12)	19(40.8)	16(178.5)
$0.25/mcf	year(feet)	13(10)	11(74.7)	8(214.5)

[a] Poor water has a saturated thickness of 75 feet and a lift of 75 feet, Fair water has a saturated thickness of 125 feet and a lift of 175 feet, and Good water has a saturated thickness of 250 feet and a lift of 250 feet.

[b] The analysis was for 25 years, but irrigation was terminated when saturated thickness was reduced to 10 feet or when irrigation is no longer profitable. Saturated thickness is in parentheses.

[c] Includes a present salvage value of groundwater remaining after 25 years.

irrigation system. In addition, physical exhaustion of the groundwater, defined as 10 feet of saturated thickness, occurred except in the case of sprinkler irrigation and a per annum increase in the natural gas price of $0.25 per mcf. Even then, economic exhaustion occurred just short of physical exhaustion. With the price of natural gas constant at $1.50 per mcf, irrigation was continued longer in Fair and Good water than in Poor water. The results indicated that if the price of gas increased annually at $0.10 per mcf, irrigation would continue the longest in Fair water. If the price rose annually at $0.25 per mcf, irrigation would be expected to continue longest in a Poor water situation. The combination of both higher natural gas price and increased lift of Fair and Good water appreciably accelerated the economic exhaustion of the water supply.

Owner and Renter Comparison

Temporal effects of a rising natural gas price were extended to include the renter-operator to provide comparisons to the owner-operator. Temporal effects, both physical and economic, were first considered with the price of natural gas held constant at $1.50 per mcf under sprinkler furrow irrigation, then again with the price of natural gas increased $0.10 per mcf per annum.

Sprinkler Irrigation.

Presented in Table 16 are cropping patterns for sprinkler and furrow irrigation, given a

Table 16. A Comparison of an Owner-Operator and Renter-Operator with Constant Natural Gas Price[a], on 640 Acres, a Typical Farm: Texas High Plains.

Item	Unit	Owner/Operator				Renter			
		Poor Water		Good Water		Poor Water		Good Water	
		Year 1	Year 14	Year 1	Year 25	Year 1	Year 14	Year 1	Year 25
Sprinkler									
Crops:									
Sorghum (dryl)	acres	106.7	211.9	106.7	106.7	106.7	211.9	106.7	106.7
Sorghum (irri)	acres	533.3	428.1	533.3	533.3	533.3	428.1	533.3	533.3
Acres irrigated	acres	533.3	428.1	533.3	533.3	533.3	428.1	533.3	533.3
Lift	feet	79.80	138	254.80	370.80	79.80	138	253.90	311.80
Saturated thickness	feet	70.17	11.97	245.17	129.23	70.17	11.97	246.14	153.38
Well yield	gpm	370	105	800	571	370	105	800	656
Water decline	feet	4.83	3.10	4.83	4.83	4.83	3.10	3.86	3.86
Water pumped	acft	667	428	667	667	667	428	533	533
Returns[b]	dol.	49985	32396	43398	38096	16938	12437	11696	8109
Returns to water[c]	dol.	32115	14526	25528	20226	NA	NA	NA	NA
Present value of									
Returns[b]	dol.	NA	594874	NA	845764[d]	NA	194033	NA	207682
Returns to Water[c]	dol.	NA	370812	NA	607005	NA	NA	NA	NA
Furrow									
Crops:		Year 1	Year 12	Year 1	Year 25	Year 1	Year 13	Year 1	Year 25
Sorghum (dryl)	acres	-	11.1	-	13.5	-	329.2	-	250.8
Wheat, grazing (dryl)	acres	155.7	258.7	179.4	168.1	-	-	-	-
Cotton (irri)	acres	457.9	269.2	453.4	458.4	474.1	236.6	474.2	389.3
Sorghum (irri)	acres	-	-	7.2	-	-	-	-	-
Soybeans (irri)	acres	-	100.9	-	-	-	74.2	-	-
Wheat, grazing	acres	17.3	-	-	-	-	-	-	-
Light feeders	head	72.9	62.0	-	-	-	-	-	-
Acres irrigated	acres	484.2	370.1	460.6	458.4	474.1	310.8	474.2	389.3
Lift	feet	80.43	137.24	255.30	367.45	80.44	139.36	254.30	352.76
Saturated thickness	feet	69.57	12.76	244.70	132.55	69.56	10.64	245.70	147.24
Well yield	gpm	368	110	800	581	388	120	800	627
Water pumped	acft	750	620	732	573	751	571	593	487
Water decline	feet	5.43	4.49	5.30	4.15	5.44	3.75	4.30	3.53
Returns[b]	dol.	43228	34951	35697	30555	18614	12572	13924	9711
Returns to water[c]	dol.	25358	17081	17827	12543	NA	NA	NA	NA
Present value of									
Returns[b]	dol.	NA	443912	NA	681736[e]	NA	191599	NA	245967
Returns to water[c]	dol.	NA	248995	NA	348060	NA	NA	NA	NA

[a] Constant natural gas price of $1.50 per mcf.

[b] Annual returns are net of variable and fixed costs.

[c] Annual returns to land and management of $17,870 have been deleted for each year.

[d] Includes a present value of water remaining after 25 years of $131,506.

[e] Includes a present value of water remaining after 25 years of $36,583.

constant price of $1.50 per mcf for natural gas, for an owner-operator and renter-operator. Results are presented for year 1 (initial year) and the year of economic exhaustion of water or end of the planning horizon (25 years). The initial cropping pattern for the owner-operator and renter, with sprinkler irrigation consisted of 106.7 acres of dryland grain sorghum and 533.3 acres of irrigated grain sorghum. This cropping pattern applied to both Poor and Good water resource situations. The results of this analysis suggest that irrigation would be continued for 14 years (physical exhaustion of the water supply) for an owner-operator in a Poor water situation. Grain sorghum remained the exclusive crop, but an additional 105.2 acres had shifted from irrigated to dryland production by year 14. In addition, irrigation levels had declined from 15 inches per irrigated acre to 12 inches. Annual net returns, above variable and fixed costs, declined from $49,985 in year 1 to $32,396 in year 14 (a 35.2 percent decline). The present value of annual net returns above variable and fixed costs was estimated to be $594,874. The present value of the returns to the groundwater supply was estimated to be $370,812.

For a Good water resource situation, the owner-operator maintained the initial cropping pattern and irrigation level throughout the 25-year planning horizon. At the end of 25 years, saturated thickness was reduced to 129.2 feet, which would increase lift to 370.8. Well yield was reduced to 571 gallons per minute (gpm). Annual net returns, above variable and fixed costs, declined from $43,398 to $38,096. The first year's net returns in Good water were 15 percent below those in Poor water, but this relationship was reversed in later years. The present value of net returns and the water supply were estimated to be $845,764 and $607,005, respectively. For the owner-operator in a Good water resource situation, the present value of the water supply includes $131,506, the present salvage value of groundwater remaining after 25 years. The present value of annual net returns for a Good water situation was 42 percent above those in Poor water. This suggests that the owner-operator in Poor water has a short-run advantage, due to reduced lift, over the owner-operator in Good water, but over time the advantage shifts to the owner-operator in Good water due to the greater quantity of available water.

The renter-operator in Poor water had the same cropping pattern, irrigation levels, and ending saturated thickness and well yield as did the owner-operator. Also, the renter irrigated the same number of years. However, a major difference is reflected in lower annual net returns (above variable and fixed costs) for the renter. Beginning and ending annual net returns to the renter were $16,938 and $12,473, which are approximately 60 percent below those of the owner-operator. The present value of annual net returns was $194,033 for the renter, or $400,841 (67 percent) below the estimated present value of net returns for an owner-operator.

In Good water, the renter once again had the same cropping pattern as the owner-operator, but he irrigated at lower levels than the owner-operator. As a result, at the end of 25 years, the saturated thickness and well yield were greater than for the owner-operator. Annual net returns above variable and fixed costs and the present value of these net returns were significantly below the owner-operator's. Beginning and ending annual net returns to the renter were $11,696 and $8,109 and were about 75 percent below the annual net returns to the owner-operator in a Good water resource situation. The present value of annual net returns to the renter was estimated to be $207,682 or $638,082 (75 percent) below the owner-operator's.

The analysis was expanded for sprinkler irrigation to include a rising natural gas price, i.e., an annual increase of $.010 per mcf. The results are summarized in Table 17. For the owner-operator in a Poor water situation, the same crops and physical changes occurred as when the gas price was a constant $1.50 per mcf. Irrigation continued for the same duration (14 years). The specified natural gas price increase reduced annual net returns from $32,115 in the first year to $11,145 in year 14. The present value of annual net returns and returns to water were $526,752 and $302,602, respectively. The increasing gas price was estimated to reduce annual net returns in the 14th year by $3,381 (a 23 percent decrease) and reduce the present value of net returns by $68,122 (a 12 percent decrease), as compared to the constant gas price analysis.

The owner-operator in Good water maintained the same cropping pattern throughout the years of irrigation. However, with the increasing gas price, irrigation levels were reduced from 15 to 12 inches per irrigated acre. Ending saturated thickness, which was at economic exhaustion of the water supply, was 178.5 feet, while the ending well yield was 729 gpm. Despite the availability of water, irrigation was no longer economically feasible and was terminated at the end of 17 years. Annual net returns (above variable and fixed costs) with higher gas prices were $18,197 in year 17, and the present value of annual net returns and of water used were $464,187 and $237,787, respectively.

The renter, faced with $0.10 per mcf increase in natural gas price in a Poor water situation, was estimated to begin with the same cropping pattern and irrigation levels as did the owner-operator. The results are summarized in Table 17. In subsequent years though, the renter shifted more acres to dryland production. In the last year of irrigation (year 16), crops included 257 dryland and 383 irrigated acres of grain sorghum. The economic impact of rising gas prices upon the renter is quite severe. Renter annual net returns (above variable and fixed costs) of $2,921 in year 14, which was the last year of irrigation by an owner-operator, were more than 80 percent below that of the owner-operator in Poor water. Annual net returns for the 16th year declined even further to $2,500, and the present value of annual net returns to the renter was $133,166 (75 percent below that of the owner-operator).

The renter with Good water was projected to have a cropping pattern of 106.7 dryland and 533.3 irrigated acres of grain sorghum throughout the irrigation period. The renter irrigated at lower levels (12 inches per irrigated acre) than did the owner-operator, and irrigation was profitable for the renter for only 7 years. Annual net returns (above variable and fixed costs) were low, $11,696 in year 1 and $3,777 in year 7 (about 75 percent below those of the owner-operator). The present value of annual net returns to the renter was $51,776 (about 75 percent below that for an owner-operator).

Furrow Irrigation. As with the sprinkler irrigation analysis, the price of natural gas was initially held constant at $1.50 per mcf and then increased by $0.10 per mcf each year. The results of the constant price analysis are presented in Table 16. The owner-operator's estimated cropping pattern, with a Poor water situation under furrow irrigation, consisted of 155.7 dryland acres (wheat and grazing) and 475.2 irrigated acres (457.9 acres cotton and 17.3 acres of wheat with grazing). The water supply was physically exhausted at the end of the 12th year, and irrigation was terminated at that point. The shift in production practices included 114 additional acres from irrigated to dryland production. Soybeans came into the solution while wheat with grazing disappeared. Annual net returns above variable and fixed costs for years 1 and 12 were $43,228 and $34,951, and the present value of annual net returns and returns to the water supply were $443,912 and $248,995, respectively.

With a Good water situation, shifts in the cropping pattern were slight for an owner-operator. Total irrigated acres remained virtually unchanged. Irrigation continued through the 25-year planning horizon with the remaining saturated thickness of the aquifer of 132.6 feet. Annual net returns above variable and fixed costs were $35,697 and $30,555 for years 1 and 25, and the present value of annual net returns and returns to water were $681,736 and $348,060, respectively. The present value of returns to water include a present salvage value for water of $36,583. As previously, the owner-operator in Poor water had a short-run advantage as reflected in higher annual net returns. But in later years the producer in Good water enjoyed greater annual returns. The physical and economic life of the water supply were greater in Good water, and the present value of returns for Good water were 54 percent above that for Poor water.

The renter in Poor water, with furrow irrigation and a constant natural gas price of $1.50 per mcf, was characterized by production of 474.1 acres of irrigated cotton. Cotton came into the solution because of the renter's share of the cotton (three-fourths) is greater than the two-thirds share he would have received from the other crops. But the total labor (which also served as a proxy for machinery constraints) was exhausted in producing the 474.2 acres of irrigated cotton, and 165.8 acres were left idle.[10] In the last year of irrigation (year 13), more acres are shown in those crops that require less water and labor. Annual net returns (above variable and fixed costs) were estimated to be $18,614 and $12,572 for years 1 and 13, approximately 60 percent below the owner-operator's annual net returns. The present value of annual net returns to the renter were $191,599, 57 percent below that of the owner-operator.

With Good water and a constant $1.50 gas price, the initial cropping pattern was the same as in Poor water (474.2 acres of irrigated cotton). Irrigation continued through the 25-year planning horizon. After 25 years the cropping pattern consisted of 250.8 acres of dryland grain sorghum while irrigated cotton declined to 389.3 acres. Ending saturated thickness was 147.2 feet. Annual net returns (above variable and fixed costs) for years 1 and 25 were $13,924 and $9,711, 60 percent below the owner-operator's annual net returns.

The effects of an annual increase in the price of natural gas of $0.10 per mcf for furrow irrigation are shown in Table 17 for the owner-operator and renter. For the

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[10] It was considered unlikely that farmers would typically leave this number of acres idle. Hence, an additional computer run was made which relaxed the labor constraints and forced into the farm plan at least 165.8 acres of dryland grain sorghum. But in the ending year of irrigation a massive shift to irrigated soybeans occurred. This was considered unrealistic, and the initial results using the labor constraints were then used in the analysis.

owner-operator in Poor water, the increasing natural gas price results relative to cropping patterns, irrigation levels, years of irrigation, etc., were exactly as occurred with a constant gas price. Annual net returns were $43,228 and $30,225 for years 1 and 12. The present value of annual net returns was $418,220, which is $25,692 (6 percent) below that with a constant gas price.

In Good water, the increasing gas prices resulted in the owner-operator terminating irrigation after 16 years with an ending saturated thickness of the aquifer of 180 feet. There was a decline in both irrigated acres (40 acres) and irrigation levels. Annual net returns above variable and fixed costs declined much more rapidly with the increasing gas prices, from $35,697 in year 1 and $18,658 in year 16. The present value of annual net returns was $390,830, or $290,916 (43 percent) less than that with a constant gas price of $1.50 per mcf.

The renter, with furrow irrigation, Poor water, and an increasing natural gas price, was estimated to have an initial cropping pattern of 474.2 acres of irrigated cotton (and 165.8 idle acres). By the last year of irrigation (year 14) a substantial shift to dryland acres occurred, and there was a reduction in the irrigation levels per acre (from 19 to 16.75 inches). Annual net returns above variable and fixed costs were $18,614 and $8,637 for years 1 and 14, respectively (about 63 percent below those of the owner-operator). The present value of annual net returns to the renter was $174,092, approximately 58 percent below that for the owner-operator and 9 percent below that for the renter with a constant gas price.

In Good water, the renter's initial cropping pattern (474.2 acres of irrigated cotton) was the same as in Poor water, but in Good water, more acres were shifted to dryland production than in Poor water. Irrigation levels per acre were maintained throughout the 11 years of irrigation. Economic exhaustion of the water supply occurred when the saturated thickness of the aquifer was reduced to 208.1 feet. Annual net returns above variable and fixed costs were $13,924 and $4,931 for years 1 and 11 (averaging about 43 percent below the annual net returns for the owner-operator, and 50 percent less than the renter's annual net return for year 11 with a constant gas price). And the present value of annual net returns to the renter was $95,448 (76 percent below the owner-operator's and over 60 percent less than the renter's with a constant gas price).

With rising natural gas prices, profitability over time for the renter-operator is low. This study implies that this is especially true in a Good water situation (with increased lift and pumping costs). The results indicate that the renter will require more land than an owner-operator to cover living expenses and to make equipment purchases or other investments. However, with a rising natural gas price, the dramatic implications for a renter suggest some rental agreements may be subject to adjustments, such as the landlord's share of crops reduced. While changes in rental terms have already occurred in a few instances (Cary 1978), pressures for changes in rental terms are likely to increase over time as natural gas prices continue to climb.

Results of the analysis suggests that the owner-operator is in a better position economically than the renter-operator, but the results apply only to the specific situations described. It does not suggest that a renter should necessarily seek to purchase land. There are barriers and risks associated with the purchase of land which dampen the incentives for the renter to purchase land. The following are some obstacles to the purchase of land:

1. purchase price of land
2. availability of loan funds
3. interest rate
4. availability of funds for down payment
5. size of annual payments
6. risk associated with fixed annual payments
7. age and/or health of purchaser

While all of these factors are important considerations in the decision to buy farmland, the overall effect of a land purchase upon the operator's financial liquidity is of vital concern (Cary 1978). A purchaser who depletes his cash reserves to make a down payment on land, borrows heavily to purchase the land, and obligates himself to sizable fixed annual payments, is assuming heavy financial risk. In the event of bad crops, low crop prices, and/or both, the land purchaser could lose the land (and his equity) to creditors and then be in worse financial condition than had he continued to farm as a renter.

Impact of Energy-Related Input Prices

While a major emphasis has been focused upon the impact of rising natural gas prices, the analysis was expanded to estimate the short-run effects of a price increase of all energy-related inputs. The inputs considered were natural gas, nitrogen fertilizer, gasoline, and diesel. The price scenarios of energy-related inputs considered in this analysis are shown in Table 18. Energy Price Scenario A was comprised of the prices which prevailed in 1978. Sceario B represented a price increase of approximately 60 percent. Computer runs were made for one year, and the results are summarized in Table 19.

With sprinkler irrigation and Poor water, the impact of increased energy prices was a reduction of annual returns above variable costs of $19,153 (21 percent). The price increases had no physical effect upon irrigation, and the quantities of the energy inputs were not responsive to these price changes of energy inputs. In the Good water situation, however, increased energy prices resulted in significant physical adjustments. Irrigated acres remained unchanged, but irrigation water applied and natural gas used were reduced 20 percent. Nitrogen fertilizer use declined 12 percent. In addition, annual returns above variable costs fell $22,550 (27 percent).

Table 18. Price Scenarios for Crops and Energy Related Inputs.

Item	Unit	Crop Price Scenarios		
		1[a]	2[b]	3[c]
Crops:				
Corn	$/Bu.	2.10	2.10	2.52
Cotton	$/Lb.	0.48	0.38	0.48
Cottonseed	$/Ton	80.00	64.00	80.00
Grain Sorghum	$/Cwt.	4.25	4.25	5.10
Soybeans	$/Bu.	5.00	4.00	6.00
Wheat	$/Bu.	3.40	3.40	4.08
Feeder Cattle:				
Lightweight	$/Lb.	0.56	0.56	0.56
Heavyweight	$/Lb.	0.52	0.52	0.52

		Energy Price Scenarios	
Energy Inputs:		A[d]	B
Gas	$/mcf	1.50	2.50
Nitrogen	$/Lb.	.16	.25
Gasoline	$/Gal.	.50	.80
Diesel	$/Gal.	.50	.80

[a] Crop Price Scenario 1 is comprised of crop prices shown in Table 6.

[b] Crop Price Scenario 2 is with prices of cotton and soybean reduced 20 percent.

[c] Crop Price Scenario 3 is with prices of grains and soybeans increased 20 percent.

[d] The prices in Energy Price Scenario A were used in all computer runs except when changed to evaluate effects of those changes.

Table 19. Static Analysis of Increased Prices of Energy Related Inputs with Two Price Scenarios[a] of These Inputs for 640 Acres, a Typical Farm: Texas High Plains.

Item	Unit	Poor Water[b] Price Scenarios A	Poor Water[b] Price Scenarios B	Good Water[b] Price Scenarios A	Good Water[b] Price Scenarios B
Sprinkler					
Crops					
Sorghum (dryl)	acres	106.7	106.7	106.7	106.7
Sorghum (irri)	acres	533.3	533.3	533.3	533.3
Level of Inputs					
Gas	mcf	8294	8294	13425	10740
Nitrogen	cwt.	874.70	874.40	874.70	768.10
Gasoline	gal.	2699	2699	2699	2699
Diesel	gal.	3491	3491	3491	3491
Water Pumped	acft	666.67	666.67	666.67	666.67
Annual Returns[c]		90129	70970	82063	59505
Furrow					
Crops					
Wheat (dryl)	acres	80.7	169.7	171.7	168
Cotton (irri)	acres	427.9	455.5	455.3	458
Sorghum (irri)	acres	-	-	-	-
Soybeans (irri)	acres	-	1.8	-	-
Wheat, Grain only	acres	109.8	13.1	9.6	-
Light Feeders	head	19	-	-	-
Wheat Pasture	aum	-	126.7	122.7	105.9
Level of Inputs					
Gas	mcf	3593	3206	8887	6881
Nitrogen	cwt.	302.90	197.90	198.50	188.10
Gasoline	gal.	2749	3520	3569	3557
Diesel	gal.	6440	7006	7014	6999
Water Pumped	acft	832	743	739	572
Annual Returns[c]	dol.	71910	62472	72059	48847

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[a] Energy price scenarios are shown in Table 18.

[b] Poor water has a saturated thickness of 75 feet and a lift of 75 feet, and Good water has a saturated thickness of 250 feet and a lift of 250 feet.

[c] Expected annual returns above variable costs.

Sizeable adjustments also occurred under furrow irrigation. In the Poor water situation, water pumped and natural gas used declined 11 percent. Sixteen percent of irrigated acres were diverted to dryland production accompanied by a 35 percent decrease in nitrogen fertilizer use. This estimated shift in cropping pattern was a reduction in irrigated wheat acres from 110 to 13, while irrigated cotton and dryland wheat with grazing increased 27.6 acres (6 percent) and 89 acres (110 percent), respectively. Annual farm returns above variable costs were lowered by $9,438 (13 percent).

In Good water, the higher price of energy-related inputs was estimated to cause irrigated acres to decline only 2 percent, but water applied and natural gas used decreased 23 percent while nitrogen fertilizer applied fell 5 percent. Further, farmer returns above variable costs were reduced 23 percent. The short-run analysis indicated that increased prices of gasoline and diesel has no appreciable effect on the quantities of these fuels demanded.

In summary, energy prices, of the magnitude considered, reduced farm returns above variable costs from 13 to 27 percent, with the greater impact being in a Good water resource situation. Irrigation water applied and natural gas used declined substantially (11 percent to 20 percent), except in Poor water with sprinkler irrigation. And nitrogen fertilizer used declined up to 35 percent. The implications of this analysis are that increased energy prices would have significant short-run effects upon irrigated agriculture, both in terms of economic consequences and the farm operation.

Crop Prices Impact

In addition to evaluating effects of input price scenarios, sensitivity of the results to crop price adjustments was investigated. The analysis was confined to consideration in a single year where returns above variable costs were the measure of profits. Three crop price scenarios, as shown in Table 18, were used. Crop Price Scenario 1, subsequently referred to as base prices, consisted of 1978 target prices, except for soybeans and beef. Since there were no target prices for soybeans and beef, average 1978 prices were used. In Crop Price Scenario 2, the prices of cotton and soybeans were reduced 20 percent, and in Crop Price Scenario 3, the prices of grains and soybeans were increased 20 percent. With furrow irrigation, cotton was the dominant crop in the farm plan (using base crop prices). Crop Price Scenarios 2 and 3 both represent a decline in the price of cotton relative to the prices of grains. The prices of these scenarios were primarily selected to determine if such price changes would force cotton out of the farm plan. A summary of the results of alternative crop prices is presented in Table 20.

Sprinkler Irrigation

With center-pivot sprinklers, annual returns above variable costs were maximized by a cropping pattern of 533.3 irrigated and 106.7 dryland acres of grain sorghum. Quite predictably, since cotton was not in the initial crops, the price changes did not result in a change in the cropping pattern or irrigation levels. The increase in the price of grain sorghum from $4.25 per cwt. in Price Scenarios 1 and 2 to $5.10 in Price Scenario 3 resulted in an increase in annual net returns from $90,129 to $122,354 (a 36 percent increase) in Poor water. In Good water, annual net returns increased from $82,063 to $114,288 (a 39 percent increase).

Furrow Irrigation

Crop price changes had a much greater impact under furrow irrigation. In Poor water, the crop prices of Scenario 1 resulted in a cropping pattern of 80.7 acres of dryland wheat and 537.7 irrigated acres. The irrigated acres included 427.9 acres of cotton and 109.8 acres of wheat with grazing. In Crop Price Scenario 2, the price of cotton was reduced 20 percent, from $0.48 to $0.38 per pound of lint. This price change resulted in adjustments in the cropping pattern. Cotton acreage disappeared, and irrigated wheat declined from 109.8 acres to 72 acres. There was a shift of 343.5 acres to irrigated grain sorghum and 143.8 irrigated acres shifted to dryland wheat. Feeder cattle increased from 19 to 75 head. Accompanying the adjustments in crops, irrigation water applied was reduced 8.7 percent. Annual net returns above variable costs fell 13.8 percent, from $71,910 to $62,007. Thus, the decreased cotton prices adversely affected annual net returns.

In Crop Price Scenario 3, the prices of grains and soybeans were increased 20 percent above those in Scenario 1. Resulting cropping pattern adjustments, compared to Scenario 1 results, included the elimination of irrigated cotton, a reduction in irrigated wheat from 109.8 acres to 65 acres, the inclusion of 358.1 acres of irrigated grain sorghum and 136.7 animal unit months (aum) of wheat pasture. Also, 136.2 additional acres were diverted to dryland wheat. Irrigation water applied was reduced 6.5 percent. Even so, annual net returns increased 21 percent, from $71,910 to $87,023.

The crop price changes had a similar impact in Good water with furrow irrigation. With crop prices of Scenario 1, crops consisted of 171.7 acres of dryland wheat, 455.3 acres of irrigated cotton, 3.4 acres of irrigated grain sorghum, 9.6 acres of irrigated wheat, and 122.7 aums of wheat pasture. Estimated annual returns above variable costs were $62,059. When the price of cotton was decreased by 20 percent (as in Crop Price Scenario 2), cotton was eliminated from the farm plan. Irrigated grain sorghum and wheat were increased 339.2 acres and 50.8 acres, respectively. In addition, 106.1 acres were shifted from irrigated production to dryland wheat, and instead of selling wheat pasture, stocker cattle were purchased to graze wheat. While total water applied to crops increased by only a small amount, the quantity applied per irrigated acre increased from 19 to 22.5 inches. And due to the heavier irrigation, the water table fell an additional .64 foot in one year. The decreased cotton price caused annual net returns to drop from $62,059 to $52,762, a 15 percent decline. The decreased cotton price not only accelerated the water table decline but also reduced annual net returns.

Grain prices of Price Scenario 3 were 20 percent higher than in Price Scenario 1. Total irrigated acres decreased by 45.7 acres (diverted to dryland wheat). Irrigated grain sorghum and wheat increased 354.7 and 55.3 acres, and instead of selling wheat pasture, stocker cattle were purchased to graze the wheat. Irrigation levels increased from 19 to 22 inches per irrigated acre, and the water table delined an additional .81 foot as compared to the decline with Price Scenario 1. The crop adjustments and the increase in irrigation levels did result in an increase in annual net returns from $62,059 to $77,536 (a 25 percent increase).

The above results indicate that under furrow irrigation, cropping patterns, irrigation levels, and annual net returns are very sensitive to the relationship among crop price changes considered.

CHAPTER VI

EFFECTS OF IRRIGATION EFFICIENCY, FINANCIAL CONSTRAINTS, AND DISCOUNT RATE

The preceding chapter dealt primarily with effects of rising natural gas prices and declining groundwater for typical farm situations of the Texas High Plains. This chapter is an extension as to the estimated effects upon the typical farm situations of improved pump efficiency, improved irrigation distribution technology, credit constraints, and alternative discount rates.

Improved pump and irrigation distribution efficiency impact on costs and irrigation water use. Credit constraints may influence the cropping pattern as well as present value of groundwater for a farm operator. Discount rate is the basis for expressing future income in terms of current dollars. Thus, it directly affects present value estimates.

It is important to note that results obtained from the model applications for the Poor water situation are applicable only to that part of the study area to the south of the Canadian River. In addition, results obtained for furrow irrigation apply only to the south of the river since cotton is included as a crop option.

Pump Efficiency

The economic and physical implications of pump efficiency were estimated by application of the recursive model assuming a 50-percent pump efficiency. The 50-percent efficiency level approximates the average pump efficiency of the Texas High Plains (Ulich 1968). A pump efficiency of 75 percent is currently attainable by the selection of the number of pump stages and the size of pump bowls that are appropriate for a given well and aquifer characteristics. Table 21 summarizes the effects of the improved pump efficiency with Poor and Good water, first with center-pivot sprinklers, then with furrow irrigation. The planning horizon for this analysis was 25 years.

Physical Implications

In the case of sprinkler irrigation and Poor water, improvement in pump efficiency from 50 to 75 percent was estimated to have no effects on farm organization. Cropping patterns, irrigation levels, and ending saturated thickness were the same for both pump efficiencies. The initial cropping pattern consisted of 640 acres of grain sorghum (106.7 dryland and 533.3 irrigated acres). By year 14 (the last year of irrigation), 105.2 additional acres reverted to dryland, after which all acres shifted to dryland production.

Sprinkler irrigation under a Good water resource situation was also characterized by grain sorghum, with 106.7 acres produced dryland and 533.3 acres produced under

Table 21. Effects of Improved Pump Efficiency for Two Water Resource Situations with Sprinkler and Furrow Distribution Systems on 640 Acres, a Typical Farm: Texas High Plains.

Item	Unit	Poor Water [a]			Good Water [a]		
		50% efficiency	75% efficiency	Difference	50% efficiency	75% efficiency	Difference
Sprinkler Irrigation							
Ending Saturated Thickness	feet	12.0	12.0	0	141.1	137.6	-3.5
Ending Well Yield	gpm	105.0	105.0	0	608.0	597.0	-8.0
Natural Gas Usage:							
Beginning	mcf/af	12.4	8.3	-4.1	20.1	13.4	-6.7
Ending	mcf/af	15.1	10.1	-5.0	24.1	16.1	-8.0
Irrigated Acres:							
Beginning	acres	533.3	533.3	0.0	533.3	533.3	0.0
Ending	acres	428.1	428.1	0.0	533.3	533.3	0.0
Years of Analysis	number	14.0	14.0	0.0	25.0	25.0	0.0
Present Value of:[b]							
Returns	dollars	585636	647576	61940	845764	943882	98118
Returns to Water[c]	dollars	361486	423426	61940	622318	847288	224970
Furrow Irrigation							
Ending Saturated Thickness	feet	12.8	12.5	-0.3	146.2	126.0	-20.2
Ending Well Yield	gpm	111.0	109.0	-1.7	623.0	561.0	-62.0
Natural Gas Usage:							
Beginning	mcf/af	4.3	2.9	-1.4	12.0	8.0	-4.0
Ending	mcf/af	6.9	4.6	-2.3	15.5	11.0	-4.5
Irrigated Acres:							
Beginning	acres	468.4	475.3	-6.9	458.4	460.6	2.2
Ending	acres	371.1	365.6	-5.5	458.4	460.6	2.2
Years of Analysis	number	12.0	12.0	0.0	25.0	25.0	0.0
Present Value of:[b]							
Returns	dollars	454874	479869	24995	681736	760833	79097
Returns to water[c]	dollars	259957	284952	24995	357983	464952	107969

[a] Poor water has a saturated thickness of 75 feet and a lift of 75 feet, and Good water has a saturated thickness of 250 feet and a lift of 250 feet.

[b] The present value of returns do not take into account the costs of well improvement. Cost of well improvement was estimated at $3,000 per well (Lyle 1978). There are 10 wells for the Poor water and 6 for the Good water.

[c] Present value of returns to water includes estimated present value of the remaining water supply after 25 years.

irrigation. The cropping patterns and irrigation level were maintained throughout the 25-year planning horizon. Over the 25 years, improved pump efficiency resulted in a greater reduction (3.5 feet) in saturated thickness and a slightly reduced ending well yield (11 gmp).

The improved pump efficiency of 75 percent had no appreciable effect on ending saturated thickness, lift, and well yield as compared to a 50-percent efficiency for furrow irrigation and Poor water. Irrigation continued for 12 years for both levels of pump efficiency, and cropping patterns were only slightly different. The initial cropping pattern included approximately 170 acres of dryland wheat with grazing and 470 irrigated acres of which 455 were cotton, less than 5 were grain sorghum, and about 10 were wheat with grazing. By the 12th year (the last year of irrigation), irrigated acres were estimated to have declined to about 370 (270 of cotton and 100 of soybeans). Dryland acres increased to 270, with about 10 acres of grain sorghum and 260 acres of wheat with grazing.

With Good water and furrow irrigation, the initial cropping pattern consisted of about the same as with the Poor water situation and was constant over the 25-year planning horizon. However, one important difference was that with the pump efficiency increased to 75 percent, irrigation levels increased, resulting in a 20.2 foot greater decrease in ending saturated thickness and a corresponding greater decline in well yield of 62 gpm as compared to the 50 percent pump efficiency estimates.

These results indicate that in Good water, with either furrow or sprinkler irrigation, improved pump efficiency will not bring about increased conservation of the groundwater supply. To the contrary, the rate of water depletion might even be accelerated. But the results did indicate that substantial economic benefits can be realized by improved pump efficiency.

Economic Implications

An improved pump efficiency from 50 to 75 percent would result in a 33 percent decline in natural gas required to pump an acre-foot of water. This constitutes a reduction in production costs, hence, an increase in producer net returns. The stream of net returns over the planning horizon, or economic life of the water supply, were discounted to give a present value figure. The increase in the present value of net returns to the producer, less cost to upgrade the well, is an estimate of the net benefits of improved pump efficiency. The costs of achieving the improved pump efficiency were estimated at $3,000 per well, hence, $30,000 for the wells in Poor water and $12,000 in Good water (Lyle 1978).

With sprinkler irrigation, improved pump efficieny (from 50 to 75 percent) increased the present value of groundwater $61,940 (17.1 percent) in Poor water and $224,970 (36.2 percent) in Good water. With furrow irrigation, the improved pump efficiency increased the present value of groundwater $24,995 (9.6 percent) in Poor water and $107,969 (30.2 percent) in Good water.

Under a Poor water resource situation and sprinkler irrigation, the increase in the present value of groundwater exceeded the estimated cost of improving pump efficiency by $31,940 ($60 per irrigated acre). With Good water, the present value of groundwater increased $212,970 ($399 per irrigated acre) above costs of well improvement. With furrow irrigation and Poor water, the increase in the present value of groundwater was $5,000 short of the estimated cost of improving pump efficiency. With Good water, the present value of returns was increased $95,969 ($208 per irrigated acre) above the estimated costs of upgrading the wells.

Improving pump efficiency from 50 to 75 percent, resulted in a 33 percent decline in irrigation fuel required to pump an acre-foot of water. With a natural gas price of $1.50, the greatest reduction in irrigation fuel costs occurred in Good water with sprinkler irrigation, in which case, irrigation fuel costs were reduced by $6,645 in year 1 and by $8,328 in year 25. The smallest reduction in irrigation fuel costs occurred in Poor water with furrow irrigation. Fuel costs were reduced by $1,600 in year 1 and $2,174 in year 12.

These results indicate that it is economically feasible to improve pump efficiency from 50 to 75 percent, except in the case of a Poor water resource situation and furrow irrigation system. The farm operator, in the cases studied, could substantially increase his net returns and reduce irrigation fuel used by an estimated 33 percent.

Distribution Efficiency

There appear to be great opportunities for improving irrigation distribution efficiency. However, there is a severe need to estimate potential benefits from the improved efficiency. Irrigation systems which are more efficient in water distribution than systems now in use have the potential of reducing irrigation fuel costs, reducing water application levels, and extending the economic life of the groundwater supply.

Furrow irrigation requires a relatively small initial investment as compared to a center-pivot sprinkler system (Cantwell 1978, Shipley 1978). Furrow irrigation has a further advantage of requiring lower water pressure than does a center-pivot sprinkler (less than 10 psi versus 90 psi). The lower pressure results in lower irrigation fuel requirements (Kletke, Harris, and Mapp 1978). However, the furrow system requires nearly three times as much labor as the center-pivot sprinklers (Extension-Economist Management). In addition, the sprinkler system provides greater control over application rates and requires less water than does furrow irrigation (Shipley 1978, Gilley and Watts 1977).

Efforts are underway to develop an irrigation system which combines desirable features of both furrow and sprinkler systems (Lyle 1978). A mobile trickle system has been devised on a trial basis that requires low water pressure (approximately the same as for furrow irrigation) and results in a very high distribution efficiency, i.e., the maintenance of yields with less runoff, evaporation, and percolation. While current stationary trickle systems are relatively labor intensive, the mobile trickle system is expected to require approximately the same labor as conventional sprinkler systems.

Sprinkler Irrigation

The analysis is concerned with estimating potential gains over time, physical or economic, that could result from a mobile trickle system as compared to a center-pivot sprinkler system.

Temporal Analysis

Temporal comparisons were made between center-pivot sprinklers and mobile trickle systems. In these comparisons, three levels of water use were considered with the mobile trickle system. The different water use levels represent different efficiencies in the distribution of water. Because a mobile trickle system is not yet on the market, a good estimate of fixed cost for the system cannot be determined. Therefore, fixed costs for the distribution systems were not considered in the comparisons, thus the estimated returns were returns to water and the distribution systems. In addition, the present values of the water supply and distribution system refer only to the 25-year planning horizon, i.e., no effort was made to determine the value of groundwater remaining after 25 years in this analysis. Conclusions regarding the benefits of improved water distribution were based upon the resulting increases in the present value of returns over 25 years plus the change in ending saturated thickness.

Since water requirements using a mobile trickle system have not been quantified, three different scenarios were assumed for the mobile trickle system: the same water use as current center-pivot sprinkler but pressure reduced to 10 psi, 25 percent less water applied, and 50 percent less water applied. For the mobile trickle system, operating pressure was set at 10 psi. In all cases, crop yields were assumed unchanged.

The difference between the present value of returns to groundwater and the distribution system for the center-pivot sprinkler system and that of the mobile trickle system sets an upper limit on the difference in the initial investment that could be economically justified to achieve improved water distribution efficiency. There is an economic benefit associated with the mobile trickle system with no water savings because the system is a low pressure system

(10 psi) which requires less irrigation fuel than a center-pivot sprinkler system (90 psi). An analysis was made for both Poor and Good water resource situations.

Results of the temporal analysis (with a gas price of $1.50 per mcf) are presented in Tables 22 and 23 for Poor water and Good water, respectively. For the center-pivot sprinkler system and the mobile trickle system (with different levels of water use), the initial cropping pattern consisted of 640 acres of grain sorghum (106.7 dryland and 533.3 irrigated). These were the beginning crops in both Poor and Good water situations. In Poor water, with center-pivot sprinklers, an additional 105.2 irrigated acres were diverted to dryland grain sorghum by the 14th year, after which irrigation was terminated. Water applied per acre was reduced from 15 inches in year 1 to 12 inches in year 14. Returns (to water and the distribution system) were $49,166 and $33,270 for years 1 and 14, and the present value of these returns was $580,959.

The mobile trickle system (with no water saved) in Poor water had the same cropping patterns, irrigation levels, and economic life of the water supply (14 years) as the center-pivot sprinkler system. But the mobile trickle system had the advantage of requiring less irrigation fuel. Returns were increased to $56,832 in year 1 (16 percent increase) and to $34,292 in year 14 (3 percent increase). The present value of these returns was $681,314, an increase

Table 22. A Comparison of Sprinkler and Mobile Trickle Irrigation Systems in a Poor Water Resource Situation at Alternative Rates of Distribution Efficiency for 640 Acres, a Typical Farm: Texas High Plains.

		Center-pivot		Mobile Trickle (10 psi)[a]					
		Sprinkler (90 psi)		No Water Saved		25% Less Water		50% Less Water	
Item	Unit	Year 1	Year 14	Year 1	Year 14	Year 1	Year 18	Year 1	Year 25
Poor Water[b]									
Crops:									
Sorghum (dryland)	acres	106.7	211.9	106.7	211.9	106.7	106.7	106.7	106.7
Sorghum (irri)	acres	533.3	428.1	533.3	428.1	533.3	533.3	533.3	533.3
Lift	feet	79.83	138.03	79.83	138.03	78.62	138.83	77.42	135.38
Saturated thickness	feet	70.17	11.97	70.17	11.97	71.38	11.18	72.58	14.62
Water decline	feet	4.83	3.10	4.83	3.10	3.62	2.93	2.92	2.42
Well yield	gpm	388	124	388	124	388	118	388	135
Water pumped	acft	667	428	667	428	500	404	333	333
Returns to[c] water and distribution system	dollars	49166	33270	56832	34292	57123	40716	59059	41429
Present value[c] of water and distribution system	dollars	NA	580959	NA	681314	NA	901888	NA	1232527

[a] The analysis is based on maintaining yields with less pressure and the same irrigation level and with 25 to 50 percent less irrigation water.

[b] Poor water has a saturated thickness of 75 feet and a lift of 75 feet.

[c] Annual returns to land and management of $17,870 per year have been deleted. Fixed costs for each distribution system have not been deleted.

Table 23. A Comparison of Sprinkler and Mobile Trickle Irrigation Systems in a Good Water Resource Situation at Alternative Rates of Distribution Efficiency for 640 Acres, a Typical Farm: Texas High Plains.

		Center-pivot Sprinkler (90 psi)		Mobile Trickle (10 psi)[a]					
				No Water Saved		25% Less Water		50% Less Water	
Item	Unit	Year 1	Year 25	Year 1	Year 25	Year 1	Year 25	Year 1	Year 25
Good Water[b]									
Crops:									
Sorghum (dryland)	acres	106.7	106.7	106.7	106.7	106.7	106.7	106.7	106.7
Sorghum (irri)	acres	533.3	533.3	533.3	533.3	533.3	533.3	533.3	533.3
Lift	feet	254.80	370.80	254.80	370.80	253.80	340.80	252.40	310.50
Saturated thickness	feet	245.17	129.23	245.17	129.23	246.38	159.42	247.58	189.50
Water decline	feet	4.83	4.83	4.83	4.83	3.62	3.62	2.42	2.42
Well yield	gpm	800	588	800	588	800	673	800	763
Water pumped	acft	667	667	667	667	500	500	333	333
Returns to[c] water and distribution system	dollars	41915	30739	50342	31563	53419	35177	56543	38518
Present value[c] of water and distribution system	dollars	NA	828789	NA	1005728	NA	1091940	NA	1174790

[a] The analysis is based on maintaining yields with less pressure and the same irrigation level and with 25 and 50 percent less irrigation water.

[b] Good Water has a saturated thickness of 250 feet and a lift of 250 feet.

[c] Annual returns to land and management of $17,870 which gives a present value over 25 years of $375,813 have been deleted. Fixed costs for each distribution system have not been deleted.

of $100,355 (17 percent increase) above the present value of returns with a center-pivot sprinkler system.

In Poor water, the mobile trickle system with 25 percent water savings maintained the same cropping pattern (106.7 acres dryland and 533.3 acres of irrigated grain sorghum) throughout the 18 years of irrigation (4 years longer than the center-pivot sprinkler). Returns to water were $57,123 and $40,716 for years 1 and 18 (14 percent and 18 percent above those with the center-pivot sprinkler). The present value of returns increased to $901,888 (55 percent).

The mobile trickle system with 50 percent water savings also had the same cropping pattern but the years for irrigation continued through year 25. The water supply was on the brink of being physically exhausted with 14.6 feet of saturated thickness remaining. Returns for years 1 and 25 were $59,059 and $41,429. The present value of returns was increased to $1,232,527, an increase of $651,568 (112 percent increase) above the center-pivot system.

Comparisons were also made in Good water between the center-pivot sprinkler system and the mobile trickle systems (with the three levels of water use). Cropping patterns were the same as for Poor water except no crop changes occurred over the 25-year planning horizon. For the 25 and 50 percent water savings situation, less water was, of course, applied than with a center-pivot system. Ending saturated thicknesses were greater by 30.2 feet and 60.3 feet with 25 percent and 50 percent water savings, respectively. Returns with a center-pivot system were $41,915 and $30,739 for years 1 and 25, respectively. As expected, net returns were higher with the mobile trickle systems. The increases in returns due to the mobile trickle systems in Good water are even more pronounced than in Poor water. Returns were increased in the range of $9,000 to $12,000 in year 1 and $2,000 to $8,000 in year 25. The highest returns were with the mobile trickle system with 50 percent water savings, $56,543 in year 1 and $38,518 in year 25. In Good water, the present value of returns to water and distribution system ranged from a low of $828,789 (center-pivot sprinkler) and to a high of $1,174,790 (mobile trickle system with 50 percent water saved).

Results give very positive indications of significant payoffs from improved distribution systems for the particular situations considered. The most notable economic gains from improved distribution efficiency were estimated to be in Poor water. These greater economic gains in Poor water were due to the combined effect of reduced lift, reduced operating pressure (resulting in decreased fuel requirements per unit volume of water pumped), and reduced total water requirements. Although greater water was available in the Good water situation, the greater lift resulted in higher irrigation costs than in Poor water, hence, less economic benefits than the Poor water situation.

The analysis was expanded to consider 1.69 million acres sprinkler irrigated on the Texas High Plains (New 1977). It was estimated that the present value of returns to water for the 1.69 million acres could be increased $446 million, $711 million, and $995 million by mobile trickle systems with three alternative water use levels, no water savings, 25 percent water savings, and 50 percent water savings, respectively. Economic gains from improved water-use efficiency would undoubtedly be increased several fold throughout the West and Great Plains. An increase in value of water represents an economic gain to society and also represents an upper limit on the cost of research that could be economically justified to achieve the improved irrigation efficiency. The magnitude of the estimates of increased value of water indicated a very significant payoff to research and development of improved irrigation distribution technology.

Static Energy Budget

Static energy comparisons for a single year were made between the irrigation distribution systems as to the total energy used by each distribution system in Good water. Table 24 summarizes these comparisons. Results show that when compared with the center-pivot system, the mobile trickle system reduced total energy by 37, 50, and 64 percent for no water savings, 25 percent savings, and 50 percent savings, respectively. The greatest reduction

Table 24. A Static Energy Use Comparison by Level of Sprinkler Distribution Efficiency for 640 Acres, a Typical Farm in Good Water[a]: Texas High Plains.

Item	Unit	Center-Pivot Sprinkler (90 psi)	Mobile Trickle System(10 psi)[b] No Water Saved	Mobile Trickle System(10 psi)[b] 25% Less Water	Mobile Trickle System(10 psi)[b] 50% Less Water
Input					
Gasoline	gal	5228	5228	5228	5228
Diesel	gal	4771	4771	4771	4771
Natural Gas	mcf	13425	8007	6020	4003
Nitrogen	lb	87466	87466	87466	87466
Insecticide	lb	267	267	267	267
Herbicide	lb	1200	1200	1200	1200
Energy					
Gasoline[d]	mil BTU[c]	627.4	627.4	627.4	627.4
Diesel[e]	mil BTU	629.8	629.8	629.8	629.8
Natural gas	mil BTU	13425.0	8007.0	6020.0	4003.0
Nitrogen[f]	mil BTU	137.8	137.8	137.8	137.8
Insecticide[g]	mil BTU	.7	.7	.7	.7
Herbicide[g]	mil BTU	3.3	3.3	3.3	3.3
Totals		14824	9406	7419	5402
Decrease in energy (mil BTU)			5418	7415	9422
Decrease in energy (%)			37	50	64

[a] Good water has a saturated thickness of 250 feet and a lift of 250 feet.

[b] Same as center-pivot sprinkler except with the operating pressure reduced to 10 psi and with no water savings, 25 percent less water used, and 50 percent less water used.

[c] Million British thermal units.

[d] Energy conversion ratio is 120,000 BTU per gallon.

[e] Energy conversion ratio is 132,000 BTU per gallon.

[f] Energy conversion ratio is 6,300 kilocalorie (kcal) per pound, the equivalent of 1575 Btu per pound, based on anhydrous ammonia at 80 percent nitrogen (Pimental, et al 1973).

[g] Energy conversion ratio is 11,000 kcal per pound of active ingredient, the equivalent of 2750 Btu per pound (Pimental, et al. 1973).

in energy use resulted with a mobile trickle system and 50 percent water savings. The reduced water use results in reduced irrigation fuel requirements. In addition, irrigation fuel requirements are reduced even further by the lower operating pressure (10 psi as compared to 90 psi) of the mobile trickle system. Such energy savings indicate strong incentives for producers to adjust to the new mobile trickle systems. And the incentives will be increasingly strong as energy becomes more scarce and costly and as irrigation fuel requirements increase due to increased lift.

In addition, potential total energy savings were estimated for 1.69 million acres of the Texas High Plains that were sprinkler irrigated (New 1977). These estimated energy savings with mobile trickle systems were the equivalent of 14.3, 19.6, and 24.9 trillion BTU's, assuming water use levels (1) the same as with center-pivot systems but lower pressure (psi), (2) 25 percent less, and (3) 50 percent less, respectively. Considering the 25 percent reduction in water use, the energy savings are equivalent to 19,568,916 mcf of natural gas. The BTU's converted to a gasoline basis represent a savings of 163 million gallons. These estimates give further indications of economic gains to society from irrigation distribution technology.

Furrow Irrigation

The purpose of this part of the study was to estimate potential gains from more uniform application of water with furrow irrigation. By shortening the row length, water can be applied more uniformly, less water is applied with no yield loss, but more labor is required. It was assumed that by cutting the length of rows in half, 25 percent water savings could be achieved. Labor requirements were doubled, and for the analysis labor was not limited. The base was with current length rows of from one-fourth and one-half mile. The base estimates were compared to model applications where the reduced water requirments and increased labor requirements had been incorporated. Table 25 summarizes the results for Poor and Good water resource situations.

In Poor water, the water supply was physically exhausted in all cases. The improved water distribution efficiency of shorter rows extended irrigation 2 years (from 8 to 10 years). Producer returns (above variable and fixed costs) were, for the first 6 years, greater with longer rows than with shorter rows, but the returns with longer rows declined more rapidly. After 6 years, producer returns were greater with short rows, particularly in years 9 ($30,176) and 10 ($27,042), since crops were not irrigated in these years where irrigation has previously been with long rows. The present values of returns (above variable and fixed costs) and returns to water were increased $79,350 (18 percent) and $48,323 (15 percent), respectively.

In Good water, irrigation continued through the 25-year

Table 25. The Effects of Water-Use Efficiency under Furrow Irrigation for 640 Acres, a Typical Farm: Texas High Plains.

Item	Unit	Water Resource Situations[a]			
		Poor		Good	
		Year 1	Year 8	Year 1	Year 25
Base					
Crops:					
Sorghum (dryl)	acres	-	64.9	-	67.7
Cotton (irri)	acres	-	287.5	177.7	305.3
Soybeans (irri)	acres	640.0	287.5	463.0	267.1
Acres irrigated	acres	640.0	575.1	640.0	572.3
Lift	feet	83.89	136.62	258.46	430.88
Saturated thickness	feet	66.11	13.38	241.54	69.12
Water pumped	acft	1227	767	1168	792
Water decline	feet	8.89	5.56	8.46	5.74
Well yield	gpm	338	146	800	387
Returns	dol.	66780	45672	52609	30236
Returns to water	dol.	48910	27802	34739	12366
Present value of:					
Returns	dol.	NA	447000	NA	918412
Returns to water[b]	dol.	NA	313227	NA	548153
With 25 percent[c] water savings		Year 1	Year 10	Year 1	Year 25
Crops					
Cotton (irri)	acres	-	357.1	-	511.4
Soybeans (irri)	acres	640.0	282.9	640.0	128.6
Acres irrigated	acres	640.0	640.0	640.0	640.0
Lift	feet	81.68	157.00	256.68	400.73
Saturated thickness	feet	68.32	12.30	243.32	99.26
Well yield	gpm	388	137	800	490
Water pumped	acft	922	685	922	666
Water decline	feet	6.68	4.90	6.68	4.83
Returns	dol.	60280	49616	50555	41757
Returns to water	dol.	42410	31816	32685	23887
Present value of:					
Returns	dol.	NA	526350	NA	950957
Returns to water[b]	dol.	NA	361550	NA	580698

[a] Poor water has a saturated thickness of 75 feet and a lift of 75 feet, and Good water has a saturated thickness of 250 feet and a lift of 250 feet.

[b] The present value of returns to water excludes the salvage value of water remaining at the end of 25 years.

[c] The basis of the analysis is that yields can be maintained with 25 percent less water applied due to shorter row lengths.

planning horizon. At the end of 25 years, the remaining saturated thickness was 30.1 feet greater where shorter rows were used, hence irrigation could be extended by using shorter rows. Returns (above variable and fixed costs) were less during the first 7 years, but were greater in subsequent years. The present value of returns (above variable and fixed costs) and returns to water used were increased by $32,545, a 6 percent increase in the present value of returns to water.

Results indicate that in the short-run (through 6 years), the use of shorter rows resulted in smaller returns, but in the long-run, shorter rows and more carefully applied water resulted in more water available in future years and increased present value of returns to water. Expanding the analysis to cover the 4.7 million acres that are furrow irrigated on the Texas High Plains (New 1977), it is estimated that the present value of returns to water would be increased by nearly $250.4 million by improving efficiency of furrow irrigation. Thus, this study indicates that significant economic benefits can be realized by the more efficient application of irrigation water (using shorter rows). The gains thus achieved entail minimal costs (primarily for increased labor) and minimal risk.

Credit Constraints

Many farmers rely heavily upon borrowing to service debts and to pay current operating and living expenses. A farmer whose ability to borrow is overly restricted might find his farm organization and profitability adversely affected. Additionally, a farmer who, of his own choosing, restricts his borrowing (due to risk aversion) might find his farm organization and profitability similarly affected.

This analysis considered only that borrowing which was for the purpose of paying operating expenses (variable costs). Hence, borrowing for capital purchases and living expenses were not considered in this evaluation.

A constraint on total credit was imposed for the analysis. In effect, a capital budget was established to cover operating costs for the production year. Throughout the year, the operator could draw upon this budget until depleted. The limit for total credit was first set at $150,000 (high enough to be non-constraining) and then reduced parametrically, in $5,000 increments, to a low of $30,000 to provide estimates of the effects of constraints of total credit. In the situations considered (Poor and Good water and sprinkler and furrow irrigation), total credit limits of greater than $80,000 (for 640 acres) had no effects, physical or economic, on the typical farm.

As credit limits were reduced below $80,000 (in $5,000 increments) changes began to occur in irrigation levels and the number of acres irrigated. With sprinkler irrigation, irrigation levels began to decline when credit limits were reduced to $70,000 in Good water ($109 per acre) and $65,000 in Poor water ($102 per acre). In Poor water, idle acres came into the solution as credit limits dropped to $60,000 or $84 per acre. Results indicate that when credit is constraining, it is more profitable to use limited operating funds to produce with irrigation than to produce dryland. Idle acres increased as credit limits were lowered. In Good water, irrigation levels continued to decline and additional acres continued to shift to dryland production as credit limits were lowered. No acreage was left idle in Good water.

With furrow irrigation, similar changes began to occur in irrigation levels and the number of acres irrigated with a credit limit of $75,000 (in both Poor and Good water). In Poor water, there were 22 acres idle without credit constraints (labor was constraining), and as the credit limit was decreased in $5,000 increments, additional acres dropped from production. In Good water, additional acres were shifted to dryland. No acres remained idle.

Credit limits reduced below $80,000 affected annual net returns (above variable costs), marginal net returns, and the marginal value product (MVP) for credit (borrowing). These are shown in Figure 17. The marginal net returns shown are the increases (decreases) in annual net returns which occur as borrowing is permitted to increase (decrease) in $5,000 increments. Hence, there are costs associated with credit limitations in terms of reduced

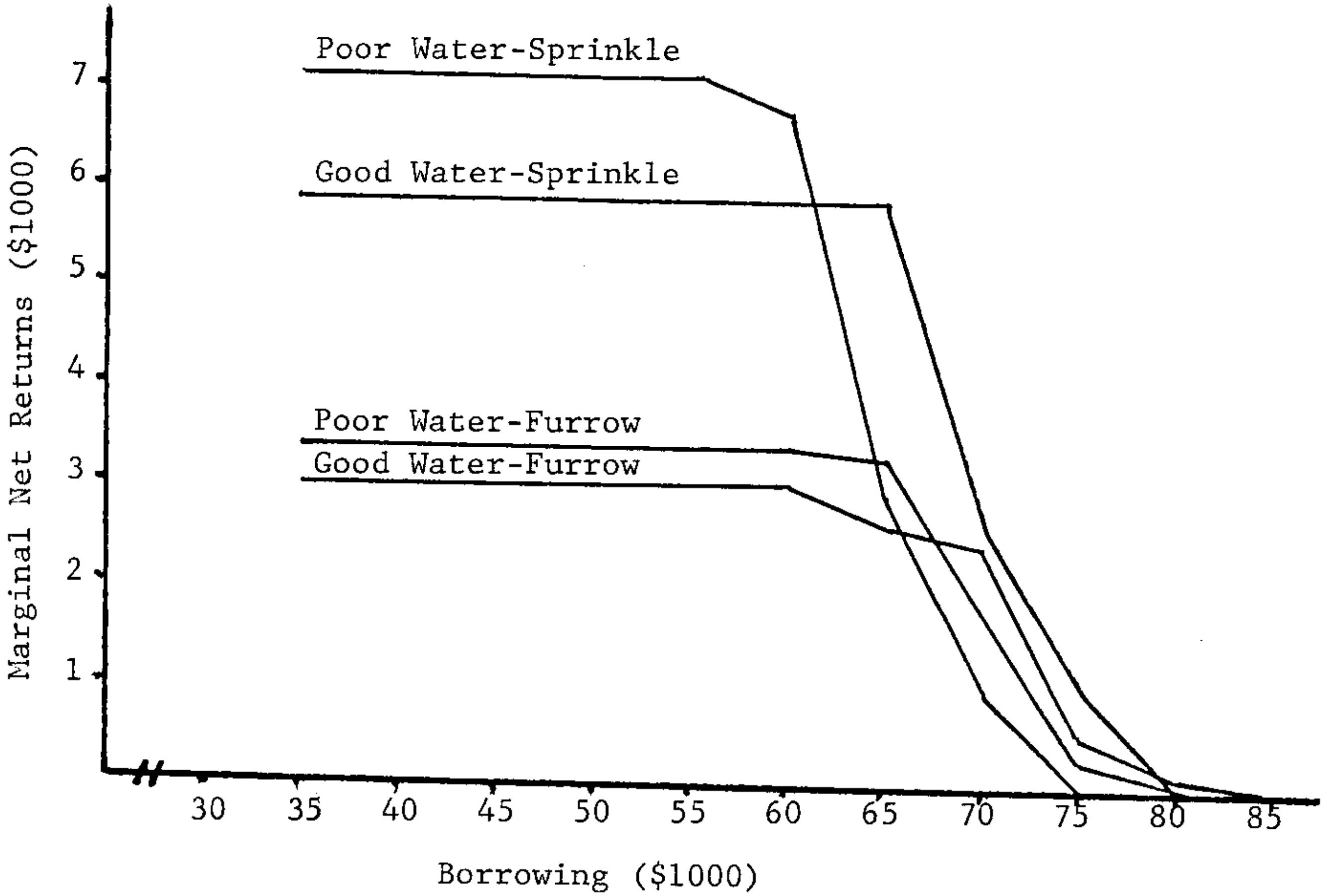

Figure 17. Marginal returns associated with an additional $5,000 credit at alternative levels of borrowing capacity for 640 acres, a typical farm: Texas High Plains.

annual net returns. The results obtained by applications of the static linear programming model estimate the costs of credit restrictions for the typical farm.

The first sizable reductions in annual net returns occurred when credit restrictions were reduced from $70,000 to $65,000 (as reflected in Figure 17), with even greater reductions in annual net returns with each additional $5,000 decrease in credit restrictions. The results suggest that if credit available for operating costs declines below $70,000 ($109 per acre), annual net returns will decline rapidly with decreasing available credit. The marginal value product (MVP), as shown in Table 26, indicates that if available credit is reduced from $60,000 ($94 per acre), annual net returns will decline $1.29 (with Poor water and sprinkler irrigation) as available credit is decreased $1.00. With Good water and furrow irrigation, the same decrease in available credit would reduce annual net returns by $0.40. These results indicate that availability of credit is probably of much greater consequence than interest rates currently being paid. The farmer could afford to pay very high interest rates in preference to not having credit available as needed.

The results also suggest that if a farmer elects to reduce borrowing in order to maintain or increase his credit reserve (unused borrowing capacity), the cost of maintaining or increasing that reserve can be substantial. Making an initial assumption that the farmer's credit is not externally rationed, the costs of credit reserves can be estimated. A credit reserve is the difference between the maximum amount that could be borrowed and the actual amount borrowed. As credit reserves were increased, annual net returns were decreased by greater amounts. With Poor water and sprinkler irrigation, maximum borrowing was $66,896. Credit reserves of $1,896, $6,896, and $11,896 reduced annual net returns by $1,024, $4,057, and $10,881, respectively. With Good water and sprinkler irrigation, the maximum amount borrowed was $74,592, and from that, credit reserves of $4,592, $9,592, and $14,592 reduced net returns $1,075, $3,750, and $9,622, respectively.

With furrow irrigation, costs of credit reserves were significantly lower than with sprinkler irrigation. In Poor water, the maximum borrowed was $76,858 and credit reserves of $1,858, $6,858, and $11,858 reduced net returns $19, $305, and $2,248, respectively. And in Good water, the maximum borrowed was $76,051. Credit reserves of $1,051, $6,051, and $11,051 caused net return reductions of $118, $708, and $3,138, respectively.

While credit reserves are of great value in coping with the unexpected, the costs of maintaining credit reserves should be recognized and considered as production plans are made. This analysis indicates proper planning is especially critical for sprinkler irrigation.

Discount Rate

The discount rate used to discount future returns is important because it affects the present value of future returns. Higher discount rates should be used when future returns are uncertain, i.e., discount rates should be adjusted upward for increased risk. The higher the discount rate used, the less will be present values of future returns.

The purpose of this section is to investigate the effects of a risk-adjusted discount rate upon the present value of annual net returns. Table 27 shows the present values of annual returns above variable and fixed costs, first, with a discount rate of 1.5 percent, used as risk-free discount rate, reflecting a time-preference for returns, and secondly, with a discount rate of 6 percent. The 6-percent discount rate included an additional 4.5 percent as a risk-adjustment factor. The risk-adjustment factor was included as an allowance for risk (arrived at subjectively) and was not the result of a measurement of risk. While the risk-adjustment factor does not affect risk itself, it does result in lower present values being assigned to future (and less certain) returns.

The higher discount rate had a greater impact on present values in Good water as compared to Poor water. This is due to the greater returns realized in Good water in later years of irrigation. Further, the higher discount rate had a lesser impact on present values with increasing

Table 27. Effects of Discount Rates upon the Present Value of Net Returns[a] with Constant and Increasing Natural Gas Prices for 640 Acres, a Typical Farm: Texas High Plains.

Item	Discount Rate			
	1.5%		6.0%	
	Water Resource Situation[b]		Water Resource Situation[b]	
	Poor	Good	Poor	Good
	---------------------(dollars)---------------------			
Constant gas price[c]				
Sprinkle irrigation	594874	845755	445123	528173
Furrow irrigation	443912	681736	344396	427220
Increasing gas price[d]				
Sprinkle irrigation	526752	464187	398664	342916
Furrow irrigation	418220	390820	326639	289644

[a] These present values of net returns are applicable only for the economic life or 25 years, whichever is shorter.

[b] Poor water has a saturated thickness of 75 feet and a lift of 75 feet, and Good water has a saturated thickness of 250 feet and a lift of 250 feet.

[c] The constant natural gas price was $1.50 per mcf.

[d] The increasing natural gas price began at $1.50 per mcf and rose $0.10 per mcf per year.

natural gas prices. This was due to the smaller returns in the latter years of irrigation, resulting from rising gas prices. The increased discount rate reduced the present value of net returns over a range from 22 to 38 percent. The greatest reduction in the present value of returns was $317,582 (a 38 percent decline) for Good water and sprinkler irrigation. The least reduction in the present value of returns occurred with Poor water, furrow irrigation, and a rising natural gas price. In this case, the present value of returns was reduced $91,581 (down 22 percent).

CHAPTER VII

SUMMARY AND CONCLUSIONS

Introduction

The economic survival of many of the region's farm units is threatened by the combination of declining groundwater, increasing irrigation fuel requirements (due to increased lift), and escalating energy prices, especially higher natural gas prices. Lower well yields, increased lift, and higher fuel costs provide incentives to apply less irrigation water which may result in lower crop yields.

This study was designed to evaluate, for typical farm situations within a 21-county sub-region of the Texas High Plains, the physical and economic effects of rising natural gas prices, pump efficiency, irrigation distribution efficiencies, tenure arrangements, and the economic effects of credit constraints. This analysis included a center-pivot sprinkler system and a furrow irrigation distribution system.

The Model

A generalized linear programming/Fortran simulation model was developed for a typical Texas High Plains farm. Three water resource situations were specified. Poor water is defined as 75 feet of lift and 75 feet of saturated thickness, Fair water as 175 feet of lift and 125 feet of saturated thickness, and Good water as a lift of 250 feet and a saturated thickness of 250 feet.

For static analysis, annual computer runs were made using only the LP component of the model. For a temporal analysis, the LP and the Fortran components were employed. The temporal analysis was recursive. Annual farm plans were developed by use of the LP model. Based on quantity of irrigation water applied in the LP farm plan, the Fortran component calculated the decline in the saturated thickness of the aquifer, and resulting new well yield, lift, and fuel required to pump water to the surface. Then the Fortran component updated the LP component with these parameters. This procedure continued automatically for 25 years of analysis or until economic exhaustion of the groundwater supply, whichever occurred first.

The LP component of the model contained production activities for irrigated crops (corn, cotton, grain sorghum, soybeans, wheat, and grazing of wheat by cattle) and dryland crops (cotton, grain sorghum, wheat, and grazing of wheat by cattle). Irrigation activities were included for both furrow or center-pivot sprinkler distribution systems. Cotton was included in the model with furrow irrigation only, since cotton is not traditionally irrigated with sprinkler systems. Since furrow irrigation included cotton, results of the furrow irrigation analysis are not applicable to the north of the Canadian River.

In addition to the production activities, there were separate purchasing activities for inputs, selling activities for crops produced, and borrowing and repaying activities.

Results

Energy Price Impacts

Energy prices were evaluated as to their effects upon a typical Texas High Plains farm. While these energy inputs included natural gas, nitrogen fertilizer, gasoline, and diesel, attention was focused primarily on natural gas.

Natural Gas Price

Expected short-run (static analysis) and longer-run (temporal analysis) effects of increased natural gas prices are summarized for a typical farm in the Texas High Plains. The discussion includes both physical and economic effects.

Static Analysis. For the base situation (which is a natural gas price of $1.50 per mcf), short-run farm returns above variable costs for an owner-operator were the greatest ($90,129) with a combination of shallow lift and lower cost of sprinkler irrigation. Annual returns above variable costs were the least with a combination of Good water and furrow irrigation ($62,059).

The price of natural gas was increased parametrically from $1.50 to $10.00 per mcf to evaluate the short-run effects of increased natural gas prices. With sprinkler irrigation and a natural gas price of $1.50 per mcf, the cropping pattern consisted entirely of 640 acres of grain sorghum, of which 533.3 acres were irrigated. As the price of natural gas was increased, irrigation levels were reduced, and in Good water, all acres reverted to dryland production when the price of natural gas reached $7.09 per mcf.

With furrow irrigation, increases in the price of natural gas resulted in adjustments in irrigation levels and shifts toward crops requiring less water. All acres shifted to dryland production at a gas price of $7.83 per mcf. The adjustments under furrow irrigation were at higher natural gas prices than with the sprinkler, but this was probably due to cotton being included as a crop option under furrow irrigation.

Annual returns above variable costs declined rapidly with increased gas prices. In Poor water, when the gas price was increased from $1.50 to $3.60, annual net returns for the owner-operator were reduced to 19 percent, while in Good water, annual net returns were reduced 30 percent. With furrow irrigation and Poor water, a gas price increase from $1.50 to $3.75 per mcf reduced annual net returns 11 percent for an owner-operator, while in Good water, the same gas price increase reduced annual net returns for an owner-operator 26 percent.

Temporal Analysis. This analysis considers returns above all costs (fixed and variable) and includes all the years to economic exhaustion of the water supply or 25 years, whichever occurs first. The base of comparison is a constant $1.50 per mcf for natural gas. The Good and Poor water resource situations were evaluated.

Estimated annual returns above variable and fixed costs in the earlier years are greatest in a Poor water situation, but less water is available in a Poor water situation and is depleted more rapidly than in Good water. With a constant natural gas price ($1.50 per mcf), irrigation can be maintained longer in a Good water situation. Thus, in later years, the annual returns above variable and fixed costs are greater in a Good water situation than in Poor water. In addition, with a constant natural gas price of $1.50 per mcf, the present value of returns to water are greater in Good water than in Poor water. However, with an initial gas price of $1.50 per mcf that is increased by $0.10 or $0.25 per mcf each year, the present value of returns to water over a 25-year planning horizon are greater in a Poor water situation than in Good water. The water that is available in future years becomes increasingly costly to pump as the water table declines and the price of irrigation fuel increases. With an initial natural gas price of $1.50 per mcf that is increased $0.25 per mcf each year, the economic life of Good water is dramatically shortened from greater than 25 years to only 8 years.

With sprinkler irrigation and Poor water, the present value of groundwater decreased 18 percent and 46 percent when the natural gas price (initially $1.50 per mcf) was increased by $0.10 and $0.25 per mcf, respectively. In Good water, the same gas price increases reduced the present value of groundwater by 61 and 84 percent, respectively.

With furrow irrigation and Poor water, natural gas price increases of $0.10 and $0.25 per mcf (from an initial $1.50 per mcf) decreased the present value of groundwater by 25 percent and 36 percent, respectively. In Good water, the same gas price increases reduced the present value of groundwater by 60 percent and 79 percent, respectively.

Rising natural gas prices resulted in the renter-operator making adjustments in cropping patterns and reducing irrigation levels in similar fashion to the owner-operator but at lower natural gas prices. With natural gas prices increasing yearly $0.10 and $0.25 per mcf (from $1.50 per mcf), annual returns (above variable and fixed costs) to a renter and the present value of those annual returns were estimated to be between 60 to 75 percent below annual returns to an owner-operator.

Energy-Related Input Prices

The base energy prices were: $1.50 per mcf for natural gas, $0.16 per pound for nitrogen fertilizer, and $0.50 per gallon for gasoline and diesel. An energy price increase of the specified magnitude (a price increase of about 60 percent) reduced returns above variable costs over a range of 13 to 27 percent. The greatest reduction in returns above variable costs occurred in Good water with sprinkler irrigation. Returns dropped from $82,063 to $59,505 (a 27 percent decrease). At the same time, both natural gas used and the volume of irrigation water applied declined 20 percent. No change in cropping patterns occurred.

In the case of Poor water with furrow irrigation, the higher energy prices decreased annual returns above variable costs from $71,910 to $62,472 (down 13 percent). Natural gas used and water pumped dropped 11 percent, and a sizable shift from irrigated wheat to dryland wheat and irrigated cotton occurred.

Crop Prices

The specific crop price scenarios used in the analysis were selected primarily to estimate the sensitivity of the farm organization and net returns under furrow irrigation. Cotton was the dominant crop (under furrow irrigation) prior to the crop price changes. With either a 20-percent decrease in cotton price or a 20-percent increase in grain prices, dramatic shifts occurred away from cotton acres to irrigated grain sorghum and dryland wheat with grazing. In

Poor water, these crop price changes decreased annual water use, while Good water, annual water use was increased. In both Poor and Good water, annual returns above variable costs decreased (14 percent) with the lower cotton price and increased (15 percent) with the higher grain peices.

Since cotton was not included as a crop option under sprinkler irrigation, the decrease in the cotton price had no effect on the cropping patterns, irrigation levels, or natural gas usage. The 20 percent increase in grain prices (specifically, the increase in the price of grain sorghum from $4.25 to $5.10 per cwt.) resulted only in increased annual returns above variable costs (a 36 percent increase in Poor water and a 39 percent increase in Good water).

Pump Efficiency

The economic and physical implications of pump efficiency were estimated by application of the recursive model with a 50 percent pump efficiency and comparing the results to a 75 percent pump efficiency over a 25-year planning horizon.

In the case of sprinkler irrigation and Poor water, the improved pump efficiency had no effect upon cropping patterns, irrigation levels, or ending saturated thickness, but natural gas usage per acre foot of water pumped was reduced 33 percent. The reduction in pumping costs resulted in an increase of $61,940 (17 percent) in the present value of the improved pump efficiency slightly increased the rate at which the water supply was being depleted and increased the present value of returns to water by $224,970 or 36 percent.

With furrow irrigation and Poor water, the effects of improved pump efficiency upon ending saturated thickness, irrigated acres, and well yield were very small, but natural gas usage was reduced 33 percent. In Good water, the physical effects were substantial. Natural gas usage was reduced 33 percent, while irrigation levels were increased. The improved pump efficiency resulted in economic exhaustion of water at a reduced saturated thickness of the aquifer. The improved pump efficiency increased the present value of returns to water by $24,995 (10 percent) and $107,969 (30 percent) in Poor and Good water situations, respectively. Expected cost to improve efficiency of assumed pumps in the Poor water situation would be $30,000, while in the Good water resource situation it would be $12,000. Only in a Poor water situation, with furrow irrigation, does it appear economically infeasible to improve pump efficiency from 50 to 75 percent.

Distribution Efficiency

The purpose of this analysis was to quantify potential economic gains resulting from improved irrigation distribution efficiency.

The analysis indicated that the water savings, due to improved distribution efficiency of a mobile trickle system, would result in the economic life the water supply being significantly extended up to 11 years in Poor water. In Good water the increase in the economic life of the water supply was not determined, but at the end of 25 years, saturated thickness of the aquifer was 60 feet greater for the mobile trickle system under the assumption of 50 percent less water used, as compared to a center-pivot system in Good water. Even though the 60 foot greater saturated thickness is not considered in the present value of returns to water, it is recognized as a beneficial factor of irrigation since well yield is greater and lift less.

The recursive model was applied to simulate a mobile trickle system, first, with the same water requirements as for a center-pivot sprinkler system but with pressure reduced from 90 psi to 10 psi, secondly, with 25 percent less water used and, thirdly, with 50 percent less water used. In all cases crop yields were held constant. In Poor water, the present value of returns to water and the distribution system were increased by \$100,355 (17 percent), \$320,929 (55 percent), and \$651,568 (112 percent), for the respective levels of water use. In Good water, the present value of returns to water and the distribution system were increased by the mobile trickle system by \$176,939 (21 percent), \$263,151 (32 percent) and \$346,001 (42 percent) for the respective levels of water use.

The analysis of the mobile trickle systems was expanded to include 1.69 million acres sprinkler irrigated on the Texas High Plains. It was estimated that the present value of returns to water for the 1.69 million acres could be increased $446 million, $711 million, and $995 million by mobile trickle systems with no water savings but reduced pressure (from 90 psi to 10 psi), 25 percent less water used, and 50 percent less water used, respectively.

Estimates were made of the total energy used by a center-pivot sprinkler system and by a mobile trickle system. According to these estimates, mobile trickle irrigation systems could potentially reduce total energy use on a 640 acre farm by 37, 50, 64 percent when the level of water use was alternatively the same as with center-pivot sprinklers but only 10 psi of pressure, 25 percent less water used, and 50 percent less water used.

Potential gains that could be realized with furrow irrigation were estimated by reducing row length and applying irrigation water more uniformly, thereby requiring 25 percent less water than long-row furrow irrigation. Results of the analysis indicate that in the short-run the use of shorter rows resulted in smaller net returns, but in the long-run, shorter rows and more carefully applied water resulted in more water being available in future years and increased present value of returns to water. The short-row furrow irrigation increased the present value of returns to water by $48,323 (15 percent) in Poor water and $32,545 (6 percent) in Good water. Additionally, it was estimated that for the 4.7 million furrow irrigated acres of the Texas High Plains, the present value of returns to water would be increased nearly $250.4 million by adopting shorter row lengths.

Credit Constraints

Credit constraints were evaluated to estimate their effect upon a typical farm on the Texas High Plains. With sprinkler irrigation, irrigation levels and annual returns began to decline when credit limits were reduced to $70,000 in Good water ($109 per acre) and $65,000 in Poor water ($102 per acre). With furrow irrigation, irrigation levels, irrigated acres and annual returns began to decline when credit limits were reduced to $75,000 (in both Poor and Good water). At the $60,000 level of borrowing, the marginal value of product (MVP) for credit was $1.29 with Poor water and sprinkler irrigation. This indicates that if available credit was reduced by $1.00, annual net returns would be reduced $1.29. With Good water and sprinkler irrigation, a $1.00 decrease in available credit would result in a $0.40 decrease in annual net returns.

The analysis also considered the cost of credit reserves (unused borrowing capacity) to the farmer. The costs of maintaining credit reserves showed to be much greater with sprinkler irrigation, i.e., credit reserves of $6,896 reduced net returns $4,057, while a credit reserve of $11,896 reduced net returns $10,881. Credit reserves can be of great value to the farmer in coping with the unexpected, but the costs of maintaining credit reserves should be recognized and considered as production plans are made.

Discount Rate

Each stream of annual net returns above variable and fixed costs was discounted first at a rate of 1.5 percent and alternatively at a rate of 6 percent. The increased discount rate reduced the present value of net returns over a range of 22 to 38 percent, the greatest reduction (38 percent) occurring with the combination of Good water, sprinkler irrigation and constant gas price. The least reduction in the present value of returns from using a 6 percent discount rate (as compared to 1.5 percent) was 22 percent and occurred in the situation of Poor water, furrow irrigation, and a natural gas price rising $0.10 per year.

The discount rate had no effect on cropping patterns or irrigation levels. This was because annual returns were maximized for each year individually, without consideration for the discount rate to be used.

Conclusions

The analysis indicated that, in the short-run, increased natural gas prices would impact most heavily upon annual net returns above variable costs. Changes in cropping patterns, irrigation levels, and natural gas usage would be expected if natural gas prices increased beyond $2.00 per mcf. The results indicate that in the short-run, with a natural gas price of $1.50 per mcf or higher, the reduced lift of a small groundwater supply outweighs the benefits of a large, deep groundwater supply.

Temporal analysis indicated that, in the long-run, rising natural gas prices, if unaccompanied by higher crop prices, can reduce annual returns by more than 30 percent and the present value of groundwater by as much as 80 percent. While the effect of rising natural gas prices upon land values was not directly evaluated, economic theory suggests that land values would be lowered and owner equity in farmland would erode. Further, the economic life of deep groundwater can be shortened because of higher gas prices, making less water economically recoverable. Rising natural gas prices have greater impact in a deep water situation due to the greater lift required to pump water to the surface.

With the problem of a declining groundwater supply and rising natural gas prices, producers must develop and adopt new technologies that will enable them to make more efficient use of remaining groundwater, extending the economic life of groundwater, and also to make more efficient use of natural gas so as to minimize irrigation pumping costs. Results of the analysis suggest that substantial economic gains are possible through improved pump efficiency and through irrigation systems which are more efficient in the distribution of water than systems currently in use. The results indicate that improved pump efficiency will not increase the economic life of the water supply, but will improve farm profits over time (increase the present value of net returns) and have a dramatic impact on energy used for irrigation.

Annual returns above variable and fixed costs were significantly increased by the improved distribution efficiency of a mobile trickle system. The present value of returns to water and the distribution system were of such magnitude that large costs could be justified to achieve the improved distribution efficiency of the mobil trickle system.

Similarly, it can be concluded that long-run gains could be realized by using shorter rows (in furrow irrigation) and applying irrigation more uniformly and with less waste. The gains that are thus achieved entail minimal costs and risk.

Thus, energy represents a threat to economic viability of an irrigated farm on the Texas High Plains. However, there are a variety of strategies that will reduce requirements for water and irrigation fuel.

The economic life of the groundwater on the Texas High Plains will be affected by several factors. These include the price of natural gas to the farmer, natural gas requirements, price of crops, and new irrigation techniques. With current irrigation technology, rising natural gas prices could lead to economic exhaustion of deep groundwater (where natural gas requirements are great) in 8 years (decreased from an economic life of over 25 years). The economic life of shallow groundwater would be less affected by rising natural gas prices. New irrigation technologies, if developed and adopted, would tend to offset increasing irrigation costs and extend the economic life of the groundwater.

Limitations in borrowing (whether imposed externally, as by a banker, or internally, as by the farmer himself) can substantially reduce annual net returns. The farmer can justify very high costs for borrowing rather than a reduction of funds available for operating expenses. Additionally, the maintenance of liquidity by means of unused borrowing capacity can be very costly.

Limitations of the Study

The study has several limitations which are acknowledged because they affect the conclusions or inferences that might be made. The limitations are as follows:

(1) Risk was not explicitly considered by the model. Variation in yields, as from drought conditions, was not treated. The only provision for risk

was hail insurance for wheat and cotton for 60 percent of the expected value of these crops.

(2) Results obtained apply only to the specific water resource situations assumed plus assumptions pertaining to:
   (a) types of distribution system used,
   (b) product and input prices,
   (c) efficiencies of engine, pump, gearhead, and water use,
   (d) input-output relations which represent states of technology,
   (e) the rate at which annual net returns are discounted,
   (f) available labor,
   (g) level of management.

(3) The LP model determines cropping patterns that maximize annual net returns. However, the individual farmer's cropping patterns might deviate from cropping patterns that maximize annual net returns, for such reasons as follows:
   (a) personal preferences for other crops due perhaps to past experience and/or technical knowledge in producing the other crops,
   (b) farm equipment which is specifically designed for crops other than the LP

cropping patterns, and

(c) a lender's preference for other crops.

(4) The analysis did not evaluate the impact of government farm programs upon the typical farm.

(5) The analysis is for one size of farm only and does not permit the evaluation of economies of size.

(6) Cotton is included as a crop option under furrow irrigation only. Therefore, results for furrow irrigation apply only south of the Canadian River.

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APPENDIX A

PRICE SCHEDULE FOR NATURAL GAS USED FOR IRRIGATION: TEXAS HIGH PLAINS

Table 28. Cost of Natural Gas, Per Mcf, Used for Irrigation.

Total Gas (mcf)	Marginal Gas (mcf)	Marginal Rate Per Month[a] ($/mcf)	Average Cost Per Mcf ($/mcf)
1	1	3.4189	3.4189
2	1	1.6783	2.0797
10	8	2.1019	2.09669
50	40	2.0279	2.04166
100	50	1.8649	1.9533
300	200	1.7449	1.8144
500	200	1.6849	1.7726
1000	500	1.6449	1.7089
2000	1000	1.6349	1.6716

Source: (Pioneer Natural Gas Company 1979)

[a] These rates include an average fuel cost adjustment of $0.5864 per mcf.

APPENDIX B

LINEAR-PROGRAMMING MODEL EMPLOYED FOR 640 ACRES, A TYPICAL FARM: TEXAS HIGH PLAINS

Table 29. Definition of Each Linear Programming Activity.

Item	Definition
Columns (Activities or Enterprises)	
Production Activities:	
COTNDRYL	Cotton, dryland
GRSODRYL	Grain sorghum, dryland
WHETDRYL	Wheat, for grain only, dryland
WHTGDRYL	Wheat with grazing, dryland
WTGODRYL	Wheat, for grazing only, dryland
CORNSPP2	Corn, sprinkler irrigated with 1 pre-plant and 2 post-plant waterings
CORNSPP3	Corn, sprinkler irrigated with 1 pre-plant and 3 post-plant waterings
CORNSPP4	Corn, sprinkler irrigated with 1 pre-plant and 4 post-plant waterings
CORNSPP5	Corn, sprinkler irrigated with 1 pre-plant and 5 post-plant waterings
GRSOSPP0	Grain sorghum, sprinkler irrigated with 1 pre-plant watering
GRSOSPP1	Grain sorghum, sprinkler irrigated with 1 pre-plant and 2 post-plant waterings
GRSOSPP2	Grain sorghum, sprinkler irrigated with 1 pre-plant and 2 post-plant waterings
GRSOSPP3	Grain sorghum, sprinkler irrigated with 1 pre-plant and 3 post-plant waterings

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Production Activities:	
GRSOSPP4	Grain sorghum, sprinkler irrigated with 1 pre-plant and 4 post-plant waterings
WHETSPP0	Wheat for grain, sprinkler irrigated with 1 pre-plant watering
WHETSPP1	Wheat for grain, sprinkler irrigated with 1 pre-plant and 1 post-plant watering
WHETSPP2	Wheat for grain, sprinkler irrigated with 1 pre-plant and 2 post-plant waterings
WHETSPP3	Wheat for grain, sprinkler irrigated with 1 pre-plant and 3 post-plant waterings
WHETSPP4	Wheat for grain, sprinkler irrigated with 1 pre-plant and 4 post-plant waterings
WHETSPP5	Wheat for grain, sprinkler irrigated with 1 pre-plant and 5 post-plant waterings
WHETSPP6	Wheat for grain, sprinkler irrigated with 1 pre-plant and 6 post-plant waterings
WHTGSPP0	Wheat with grazing, sprinkler irrigated with 1 pre-plant watering
WHTGSPP1	Wheat with grazing, sprinkler irrigated with 1 pre-plant and 1 post-plant watering
WHTGSPP2	Wheat with grazing, sprinkler irrigated with 1 pre-plant and 2 post-plant waterings

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Production Activities:	
WHTGSPP3	Wheat with grazing, sprinkler irrigated with 1 pre-plant and 3 post-plant waterings
WHTGSPP4	Wheat with grazing, sprinkler irrigated with 1 pre-plant and 4 post-plant waterings
WHTGSPP5	Wheat with grazing, sprinkler irrigated with 1 pre-plant and 5 post-plant waterings
WHTGSPP6	Wheat with grazing, sprinkler irrigated with 1 pre-plant and 6 post-plant waterings
WTGOSPP2	Wheat graze-out, sprinkler irrigated with 1 pre-plant and 2 post-plant waterings
WTGOSPP3	Wheat graze-out, sprinkler irrigated with 1 pre-plant and 3 post-plant waterings
WTGOSPP4	Wheat graze-out, sprinkler irrigated with 1 pre-plant and 4 post-plant waterings
WTGOSPP5	Wheat graze-out, sprinkler irrigated with 1 pre-plant and 5 post-plant waterings
CORNFPP2	Corn, furrow irrigated with 1 pre-plant and 2 post-plant waterings
CORNFPP3	Corn, furrow irrigated with 1 pre-plant and 3 post-plant waterings

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Production Activities:	
CORNFPP4	Corn, furrow irrigated with 1 pre-plant and 4 post-plant waterings
CORNFPP5	Corn, furrow irrigated with 1 pre-plant and 5 post-plant waterings
CORNFFP6	Corn, furrow irrigated with 1 pre-plant and 6 post-plant waterings
COTNFPP0	Cotton, furrow irrigated with 1 pre-plant watering
COTNFPP1	Cotton, furrow irrigated with 1 pre-plant and 1 post-plant watering
COTNFPP2	Cotton, furrow irrigated with 1 pre-plant and 2 post-plant waterings
COTNFPP3	Cotton, furrow irrigated with 1 pre-plant and 3 post-plant waterings
GRSOFPP0	Grain sorghum, furrow irrigated with 1 pre-plant watering
GRSOFPP1	Grain sorghum, furrow irrigated with 1 pre-pland and 1 post-plant watering
GRSOFPP2	Grain sorghum, furrow irrigated with 1 pre-plant and 2 post-plant waterings
GRSOFPP3	Grain sorghum, furrow irrigated with 1 pre-plant and 3 post-plant waterings
GRSOFPP4	Grain sorghum, furrow irrigated with 1 pre-plant and 4 post-plant waterings

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Production Activities:	
SOYBFPP2	Soybeans, furrow irrigated with 1 pre-plant and 2 post-plant waterings
SOYBFPP3	Soybeans, furrow irrigated with 1 pre-plant and 3 post-plant waterings
SOYBFPP4	Soybeans, furrow irrigated with 1 pre-plant and 4 post-plant waterings
WHETFPP0	Wheat for grain, furrow irrigated with 1 pre-plant watering
WHETFPP1	Wheat for grain, furrow irrigated with 1 pre-plant and 1 post-plant watering
WHETFPP2	Wheat for grain, furrow irrigated with 1 pre-plant and 2 post-plant waterings
WHETFPP3	Wheat for grain, furrow irrigated with 1 pre-plant and 3 post-plant waterings
WHETFPP4	Wheat for grain, furrow irrigated with 1 pre-plant and 4 post-plant waterings
WHETFPP5	Wheat for grain, furrow irrigated with 1 pre-plant and 5 post-plant waterings
WHTGFPP0	Wheat with grazing, furrow irrigated with 1 pre-plant watering
WHTGFPP1	Wheat with grazing, furrow irrigated with 1 pre-plant and 1 post-plant watering
WHTGFPP2	Wheat for grazing, furrow irrigated with 1 pre-plant and 2 post-plant waterings

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Production Activities:	
WHTGFPP3	Wheat with grazing, furrow irrigated with 1 pre-plant and 3 post-plant waterings
WHTGFPP4	Wheat with grazing, furrow irrigated with 1 pre-plant and 4 post-plant waterings
WHTGFPP5	Wheat for grazing, furrow irrigated with 1 pre-plant and 5 post-plant waterings
WTGOFPP2	Wheat graze-out, furrow irrigated with 1 pre-plant and 2 post-plant waterings
WTGOFPP3	Wheat graze-out, furrow irrigated with 1 pre-plant and 3 post-plant waterings
WTGOFPP4	Wheat graze-out, furrow irrigated with 1 pre-plant and 4 post-plant waterings
GRAZSTK1	Graze, stocker cattle to sell at light weight (613 lbs.)
GRAZSTK2	Graze, stocker cattle to sell at heavy weight (744 lbs.)
Buy Activities:	
BUYSTOKR	Stocker steer
NATGSPR1	Natural gas for sprinkler irrigation, in cash-flow period 1
NATGSPR2	Natural gas for sprinkler irrigation, in cash-flow period 2
NATGSPR3	Natural gas for sprinkler irrigation, in cash-flow period 3

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Buy Activities:	
NATGSPR4	Natural gas for sprinkler irrigation, in cash-flow period 4
NATGSPR5	Natural gas for sprinkler irrigation, in cash-flow period 5
NATGSPR6	Natural gas for sprinkler irrigation, in cash-flow period 6
NATGFUR1	Natural gas for furrow irrigation, in cash-flow period 1
NATGFUR2	Natural gas for furrow irrigation, in cash-flow period 2
NATGFUR3	Natural gas for furrow irrigation, in cash-flow period 3
NATGFUR4	Natural gas for furrow irrigation, in cash-flow period 4
NATGFUR5	Natural gas for furrow irrigation, in cash-flow period 5
NATGFUR6	Natural gas for furrow irrigation, in cash-flow period 6
ELECSPR1	Electricity for sprinkler irrigation, in cash-flow period 1
ELECSPR2	Electricity for sprinkler irrigation, in cash-flow period 2
ELECSPR3	Electricity for sprinkler irrigation, in cash-flow period 3
ELECSPR4	Electricity for sprinkler irrigation, in cash-flow period 4
ELECSPR5	Electricity for sprinkler irrigation, in cash-flow period 5
ELECSPR6	Electricity for sprinkler irrigation, in cash-flow period 6

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Buy Activities:	
MLABORP1	Machine labor, in cash-flow period 1
MLABORP2	Machine labor, in cash-flow period 2
MLABORP3	Machine labor, in cash-flow period 3
MLABORP4	Machine labor, in cash-flow period 4
MLABORP5	Machine labor, in cash-flow period 5
MLABORP6	Machine labor, in cash-flow period 6
ILABORP1	Irrigation labor, in cash-flow period 1
ILABORP2	Irrigation labor, in cash-flow period 2
ILABORP3	Irrigation labor, in cash-flow period 3
ILABORP4	Irrigation labor, in cash-flow period 4
ILABORP5	Irrigation labor, in cash-flow period 5
ILABORP6	Irrigation labor, in cash-flow period 6
HLABORP4	Part-time hoeing labor, in cash-flow period 4
COTNINS	Hail insurance for cotton
WHETINSR	Hail insurance for wheat
CORNSEED	Corn seed
COTNSEED	Cotton seed
GRSOSEED	Grain sorghum seed
SOYBSEED	Soybean seed

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Buy Activities:	
WHETSEED	Wheat seed
CHRBCORN	Custom application of herbicide to corn
CHRBCOTD	Custom application of herbicide to dryland cotton
CHRBCOTI	Custom application of herbicide to irrigated cotton
CHRBWHTI	Custom application of herbicide to irrigated wheat
HRBATRAZ	Herbicide material (Atrazine)
HRBTREFN	Herbicide material (Treflan)
HRBPROPZ	Herbicide material (Propazine)
HRB24DDD	Herbicide material (2,4-D)
CINSCRN3	Custom application of insecticide to corn, in cash-flow period 3
CINSCRN4	Custom application of insecticide to corn, in cash-flow period 4
CINSCOTI	Custom application of insecticide to irrigated cotton
CINSGRSO	Custom application of insecticide to grain sorghum
CINSWHTI	Custom application of insecticide to irrigated wheat
FURIDAN3	Insecticide material (Furidan) in cash-flow period 3
FURIDAN4	Insecticide material ((Furidan) in cash-flow period 4
MALATHON	Insecticide material (Malathion)
METHPAR3	Insecticide material (Methyl Parathion), in cash-flow period 3

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Buy Activities:	
METHPAR5	Insecticide material (Methyl Parathion), in cash-flow period 5
NITROGN2	Nitrogen fertilizer, in cash-flow period 2
NITROGN4	Nitrogen fertilizer, in cash-flow period 4
PHOSPHOR	Phosphorous fertilizer
DIESELP1	Diesel, in cash-flow period 1
DIESELP2	Diesel, in cash-flow period 2
DIESELP3	Diesel, in cash-flow period 3
DIESELP4	Diesel, in cash-flow period 4
DIESELP5	Diesel, in cash-flow period 5
DIESELP6	Diesel, in cash-flow period 6
GASOLNP1	Gasoline, in cash-flow period 1
GASOLNP2	Gasoline, in cash-flow period 2
GASOLNP3	Gasoline, in cash-flow period 3
GASOLNP4	Gasoline, in cash-flow period 4
GASOLNP5	Gasoline, in cash-flow period 5
GASOLNP6	Gasoline, in cash-flow period 6
CORNCOMB	Custom combining of corn
GRSOCOMD	Custom combining of dryland grain sorghum
GRSOCOMI	Custom combining of irrigated grain sorghum
SOYBCOMB	Custom combining of soybeans
WHTCOMBD	Custom combining of dryland wheat

Table 29. (continued)

Item	Definition
Columns (Activities or Enterprises)	
Buy Activities:	
WHTCOMBI	Custom combining of irrigated wheat
COTNSAHL	Cotton stripping and hauling
COTNGING	Cotton ginning
CORNHAUL	Corn hauling
GRSOHAUL	Grain sorghum hauling
SOYBHAUL	Soybean hauling
WHETHAUL	Wheat hauling
CORNDRYG	Corn drying
Fixed Cost Activities:	
DRFXCEQP	Fixed cost for machinery and equipment for dryland crops (per acre)
FXCSTEQ1	Fixed cost for machinery and equipment for crops with intermediate level of irrigation (per acre)
FXCSTEQ2	Fixed cost for machinery and equipment for crops with high levels of irrigation (per acre)
SPFXCOST	Fixed cost for center-pivot sprinler irrigation system (per acre)
FRFXCOST	Fixed cost for furrow irrigation system (per acre)
Borrowing and Saving Activities:	
BORROWP1	Borrowing, in cash-flow period 1
BORROWP2	Borrowing, in cash-flow period 2

Table 29 (continued)

Item	Definition
Columns (Activities or Enterprises)	
Borrowing and Saving Activities:	
BORROWP3	Borrowing, in cash-flow period 3
BORROWP4	Borrowing, in cash-flow period 4
BORROWP5	Borrowing, in cash-flow period 5
BORROWP6	Borrowing, in cash-flow period 6
INVSTRP1	Saving, in cash-flow period 1
INVSTRP2	Saving, in cash-flow period 2
INVSTRP3	Saving, in cash-flow period 3
INVSTRP4	Saving, in cash-flow period 4
INVSTRP5	Saving, in cash-flow period 5
INVSTRP6	Saving, in cash-flow period 6
Selling Activities:	
SELLCORN	Sell corn
SELLCOTN	Sell cotton lint
SELLCTSD	Sell cotton seed
SELLGRSO	Sell grain sorghum
SELLSOYB	Sell soybeans
SELLWHET	Sell wheat
SELLPAS1	Sell wheat pasture, i.e., custom graze stocker cattle until March
SELLPAS2	Sell wheat pasture, i.e., custom graze stocker cattle until June
SELLLTFD	Sell light-weight feeder cattle (613 lbs.) in March
SELLHVFD	Sell heavy-weight feeder cattle (744 lbs.) in June

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
OBJF	Objective Function
RTOTWATR	Total irrigation water applied to crops (acre feet)
DRYACRES	Total dryland acres
DRYLCOTN	Dryland cotton acres
DRYLGRSO	Dryland grain sorghum acres
DRYLWHET	Dryland wheat-for-grain acres
DRYLWAGR	Dryland wheat-with-grazing acres
SPRACRES	Total sprinkler-irrigated acres
SPRRCORN	Sprinkler-irrigated corn acres
SPRRGRSO	Sprinkler-irrigated grain sorghum acres
SPPRWHET	Sprinkler-irrigated wheat acres, for grain only
SPRRWHGR	Sprinkler-irrigated wheat acres, for grain plus grazing
FURACRES	Total furrow-irrigated acres
FURRCORN	Furrow-irrigated corn acres
FURRCOTN	Furrow-irrigated cotton acres
FURRGRSO	Furrow-irrigated grain sorghum acres
FURRSOYB	Furrow-irrigated soybean acres
FURRWHET	Furrow-irrigated wheat acres, for grain only
FURRWHGR	Furrow-irrigated wheat acres, for grain plus grazing
FEEDERSL	Total light-weight feeder cattle (613 lbs.)

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
FEEDERH	Total heavy-weight feeder cattle (744 lbs.)
RCWATP01	Water constraint in critical water period 1, i.e., January - February (hours)
RCWATP02	Water constraint in critical water period 2, i.e., March (hours)
RCWATP03	Water constraint in critical water period 3, i.e., April (hours)
RCWATP04	Water constraint in critical water period 4, i.e., May (hours)
RCWATP05	Water constraint in critical water period 5, i.e., June (hours)
RCWATP06	Water constraint in critical water period 6, i.e., July (hours)
RCWATP07	Water constraint in critical water period 7, i.e., August (hours)
RCWATP08	Water constraint in critical water period 8, i.e., September (hours)
RCWATP09	Water constraint in critical water period 9, i.e., October (hours)
RCWATP10	Water constraint in critical water period 10, i.e. November-December (hours)
RACRESPR	Constraint on sprinkler-irrigated acres
RACREFUR	Constraint on furrow-irrigated acres
RACRETOT	Constraint on total acres
RNATGSP1	Natural gas required with sprinkler irrigation, in cash-flow period 1

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
RNATGSP2	Natural gas required with sprinkler irrigation, in cash-flow period 2
RNATGSP3	Natural gas required with sprinkler irrigation, in cash-flow period 3
RNATGSP4	Natural gas required with sprinkler irrigation, in cash-flow period 4
RNATGSP5	Natural gas required with sprinkler irrigation, in cash-flow period 5
RNATGSP6	Natural gas required with sprinkler irrigation, in cash-flow period 6
RNATGSFR1	Natural gas required with furrow irrigation, in cash-flow period 1
RNATGSFR2	Natural gas required with furrow irrigation, in cash-flow period 2
RNATGSFR3	Natural gas required with furrow irrigation, in cash-flow period 3
RNATGSFR4	Natural gas required with furrow irrigation, in cash-flow period 4
RNATGSFR5	Natural gas required with furrow irrigation, in cash-flow period 5
RNATGSFR6	Natural gas required with furrow irrigation, in cash-flow period 6
RMLABRP1	Labor for machinery and equipment required, in labor period 1
RMLABRP2	Labor for machinery and equipment required, in labor period 2
RMLABRP3	Labor for machinery and equipment required, in labor period 3
RMLABRP4	Labor for machinery and equipment required, in labor period 4
RMLABRP5	Labor for machinery and equipment required, in labor period 5

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
RMLABRP6	Labor for machinery and equipment required, in labor period 6
RMAXLAB1	Total labor constraint for January-February (hours)
RMAXLAB2	Total labor constraint for March-April (hours)
RMAXLAB3	Total labor constraint for May-June (hours)
RMAXLAB4	Total labor constraint for July-August (hours)
RMAXLAB5	Total labor constraint for September-October (hours)
RMAXLAB6	Total labor constraint for November-December (hours)
RCOTNINS	Hail insurance on cotton (dollars per acre)
RCOTNSED	Corn seed planted (pounds per acre)
RGRSOSED	Grain sorghum seed planted (pounds per acre)
RSOYBSED	Soybean seed planted (bushels per acre)
RWHETSED	Wheat seed planted (bushels per acre)
RCORNHRB	Custom herbicide treatment of corn (applications per acre)
RCOTDHRB	Custom herbicide treatment of dry-land cotton (applications per acre)
RGRSOHRB	Custom herbicide treatment of grain sorghum (applications per acre)
RWHETHRB	Custom herbicide treatment of wheat (applications per acre)

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
RATRAZIN	Required herbicide material, atrazine, per acre application (pounds of active ingredient)
RTREFLAN	Required herbicide material, Treflan, per acre application (pounds of active ingredient)
RPROPAZN	Required herbicide material, Propazine, per acre application (pounds of active ingredient)
R24DDDDD	Required herbicide material, 2,4-D, per acre application (pounds per active ingredient)
RCRNINS3	Custom insecticide treatment of corn (applications per acre) in June
RCRNINS4	Custom insecticide treatment of corn (applications per acre) in August
RCOTINST	Custom insecticide treatment of cotton (applications per acre)
RGRSINST	Custom insecticide treatment of grain sorghum (applications per acre)
RWHTINST	Custom insecticide treatment of wheat (applications per acre)
RFURDAN3	Required insecticide material, Furidan, in June (pounds of active ingredients)
RFURDAN4	Required insecticide material, Furidan, in August (pounds of active ingredients)
RMALATHN	Required insecticide material, Malathion (pounds of active ingredient)

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
RMETPAR3	Required insecticide material, Methyl Parathion in June (pounds of active ingredient)
RMETPAR4	Required insecticide material, Methyl Parathion in August (pounds of active ingredient)
RNITROG2	Required nitrogen fertilizer in April (pounds per acre)
RNITROG4	Required nitrogen fertilizer in August (pounds per acre)
RPHOSPHR	Required phosphorous fertilizer (pounds per acre)
RDIESEL1	Required diesel in cash-flow period 1, January-February (gallons per acre)
RDIESEL2	Required diesel in cash-flow period 2, March-April (gallons per acre)
RDIESEL3	Required diesel in cash-flow period 3, May-June (gallons per acre)
RDIESEL4	Required diesel in cash-flow period 4, July-August (gallons per acre)
RDIESEL5	Required diesel in cash-flow period 5, September-October (gallons per acre)
RDIESEL6	Required diesel in cash-flow period 6, November-December (gallons per acre)
RGASOLN1	Required gasoline in cash-flow period 1, January-February (gallons per acre)
RGASOLN2	Required gasoline in cash-flow period 2, March-April (gallons per acre)
RGASOLN3	Required gasoline in cash-flow period 3, May-June (gallons per acre)

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
RGASOLN4	Required gasoline in cash-flow period 4, July-August (gallons per acre)
RGASOLN5	Required gasoline in cash-flow period 5 September-October (gallons per acre)
RGASOLN6	Required gasoline in cash-flow period 6, November-December (gallons per acre)
RCCCORNN	Custom combining of corn (bushels per acre)
RCCGRSOD	Custom combining of dryland grain sorghum (acre)
RCCGRSOI	Custom combining of irrigated grain sorghum (hundred pounds per acre)
RCCSOYBN	Custom combining of soybeans (bushels per acre)
RCCWHETD	Custom combining of dryland wheat (acre)
RCCWHETI	Custom combining of irrigated wheat (bushels per acre)
RCSHCOTN	Custom cotton stripping and hauling (Hundred pounds per acre)
RGINCOTN	Cotton ginning (hundred pounds per acre)
RHAULCRN	Corn hauling (bushels per acre)
RHAULGRS	Grain sorghum hauling (hundred pounds per acre)
RHAULSOY	Soybean hauling (bushels per acre)
RHAULWHT	Wheat hauling (bushels per acre)
RDRYCORN	Corn drying (bushels per acre)
RDFXCEQP	Fixed cost for machinery and equipment for dryland crops (per acre)

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
RIFXCEQ1	Fixed cost for machinery and equipment with intermediate levels of irrigation (dollars per acre)
RIFXCEQ2	Fixed cost for machinery and equipment with high levels of irrigation (dollars per acre)
RSPFXCST	Fixed cost for center-pivot sprinkler irrigation systems (dollars per acre)
RFRFXCST	Fixed cost for furrow irrigation systems (dollars per acre)
RCASHFL1	Required dollars for variable operating cost in cash-flow period 1, January-February (dollars per acre)
RCASHFL2	Required dollars for variable operating cost in cash-flow period 2, March-April (dollars per acre)
RCASHFL3	Required dollars for variable operating cost in cash-flow period 3, May-June (dollars per acre)
RCASHFL4	Required dollars for variable operating cost in cash-flow period 4, July-August (dollars per acre)
RCASHFL5	Required dollars for variable operating cost in cash-flow period 5 September-October (dollars per acre)
RCASHFL6	Required dollars for variable operating cost in cash-flow period 6 November-December 30 (dollars per acre)
RCASHFL7	Required dollars for variable operating cost in cash-flow period 7, December 31 (dollars per acre)

Table 29. (continued)

Item	Definition
Rows (Resource Constraints or Activity Transfers)	
RSELLCRN	Sell corn (bushels per acre)
RSELLCOT	Sell cotton lint (hundred pounds per acre)
RSELLCTS	Sell cottonseed (tons per acre)
RSELLGRS	Sell grain sorghum (hundred pounds per acre)
RSELLSOY	Sell soybeans (bushels per acre)
RSELLWHT	Sell wheat (bushels per acre)
RTRPAST1	Sell wheat pasture from October-March (dollars per animal unit mouths)
RTRPAST2	Sell wheat pasture from October to June (dollars per animal unit mouths)
RBUYSTOK	Buy stocker cattle to graze wheat (dollars per pound)
RSELLLTFD	Sell light-weight feeder cattle, 613 lbs. (dollars per pound)
RSELLHVFD	Sell heavy-weight feeder cattle, 744 lbs. (dollars per pound)

Table 30. The Linear Programming Model for 640 Acres, a Typical Farm: Texas High Plains.

OBJF	4.37000-	2.08000-	2.67000-	2.67000-	2.67000-	7.72000-	9.94000-	OBJF
RTOTWATP	.	.	.	.	.	.83330	1.33330	RTOTWATP
DRYACRES	1.00000	1.00000	1.00000	1.00000	1.00000	.	.	DRYACRES
DRYLCOTN	1.00000	.	.	.	.	.	.	DRYLCOTN
DRYLGRSO	.	1.00000	.	.	.	.	.	DRYLGRSO
DRYLWHET	.	.	1.00000	.	.	.	.	DRYLWHET
DRYLWHGR	.	.	.	1.00000	1.00000	.	.	DRYLWHGR
SPRACRES	.	.	.	.	.	1.00000	1.00000	SPRACRES
SPRKCORN	.	.	.	.	.	1.00000	1.00000	SPRKCORN
RCWATP02	.	.	.	.	.	.25000	.25000	RCWATP02
RCWATP05	.	.	.	.	.	.25000	.25000	RCWATP05
RCWATP06	.	.	.	.	.	.33330	.66670	RCWATP06
RCWATP07	.	.	.	.	.	.	.16670	RCWATP07
RACRESPR	.	.	.	.	.	1.20000	1.20000	RACRESPR
RACRETOT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACRETOT
RNATGSP2	.	.	.	.	.	.25000	.25000	RNATGSP2
RNATGSP3	.	.	.	.	.	.25000	.25000	RNATGSP3
RNATGSP4	.	.	.	.	.	.33330	.83330	RNATGSP4
RMLABRP1	.82000	.33000	.12000	.12000	.12000	.46000	.	RMLABRP1
RMLABRP2	.81000	.61000	.12000	.12000	.12000	1.36000	1.36000	RMLABRP2
RMLABRP3	1.27000	.69000	.53000	.53000	.53000	.78000	.78000	RMLABRP3
RMLABRP4	.12000	.12000	.74000	.74000	.74000	.24000	.24000	RMLABRP4
RMLABRP5	.12000	.12000	.77000	.77000	.77000	.12000	.12000	RMLABRP5
RMLABRP6	1.07000	.	.12000	.12000	.12000	.	.	RMLABRP6
RILABRP2	.	.	.	.	.	.14400	.14400	RILABRP2
RILABRP3	.	.	.	.	.	.14400	.14400	RILABRP3
RILABRP4	.	.	.	.	.	.19200	.48000	RILABRP4
RCOTNINS	50.00000	.	.	.	.	.	.	RCOTNINS
RWHETINS	.	.	8.00000	7.00000	.	.	.	RWHETINS
RCORNSED	.	.	.	.	.	16.00000	17.30000	RCORNSED
RCOTNSED	15.00000	.	.	.	.	.	.	RCOTNSED
RGRSDSED	.	3.00000	.	.	.	.	.	RGRSOSED
RWHETSED	.	.	.50000	.50000	.50000	.	.	RWHETSED
RCORNHFB	.	.	.	.	.	1.00000	1.00000	RCORNHFB
RCOTDHRB	1.00000	.	.	.	.	.	.	RCOTDHRB
RCRNINS3	.	.	.	.	.	1.00000	1.00000	RCRNINS3
RCRNINS4	.	.	.	.	.	1.00000	1.00000	RCRNINS4
RNITROG2	.	20.00000	.	.	.	120.00000	145.00000	RNITROG2
RDIESEL1	1.75000	.80000	.	.	.	1.60000	1.60000	RDIESEL1
RDIESEL2	2.93000	1.93000	.	.	.	5.10000	5.30000	RDIESEL2
RDIESEL3	3.35000	1.80000	1.13000	1.13000	1.13000	2.30000	2.30000	RDIESEL3
RDIESEL4	.	.	1.93000	1.93000	1.93000	.	.	RDIESEL4
RDIESEL5	.	.	2.60000	2.60000	2.60000	.	.	RDIESEL5

Table 30. (continued)

	COTNORYL	GRSODRYL	WHETDRYL	WHTGDRYL	WTGODRYL	CORNSPP2	CORNSPP3	
RDIESEL6	5.03000	.	.	.	.	.	.	RDIESEL6
RGASOLN1	1.10000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN1
RGASOLN2	1.10000	.55000	.55000	.55000	.55000	1.10000	1.10000	RGASOLN2
RGASOLN3	1.68000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN3
RGASOLN4	.55000	.55000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN4
RGASOLN5	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN5
RGASOLN6	.55000	.	.55000	.55000	.55000	.	.	RGASOLN6
RCCCORNN	.	.	.	.	.	93.00000	132.00000	RCCCORNN
RCCGRSOD	.	1.00000	.	.	.	.	.	RCCGRSOD
RCCWHETD	.	.	1.00000	1.00000	.	.	.	RCCWHETD
RCSHCOTN	7.00000	.	.	.	.	.	.	RCSHCOTN
RGINCOTN	7.00000	.	.	.	.	.	.	RGINCOTN
RHAULCRN	.	.	.	.	.	93.00000	132.00000	RHAULCRN
RHAULGRS	.	15.00000	.	.	.	.	.	RHAULGRS
RHAULWHT	.	.	15.00000	14.00000	.	.	.	RHAULWHT
RDRYCORN	.	.	.	.	.	93.00000	132.00000	RDRYCORN
RDFXCEQP	1.00000	1.00000	1.00000	1.00000	1.00000	.	.	RDFXCEQP
RIFXCEQ2	.	.	.	.	.	1.00000	1.00000	RIFXCEQ2
RSPFXCST	.	.	.	.	.	1.00000	1.00000	RSPFXCST
RCASHFL1	1.18000	.36000	.15000	.15000	.15000	.66000	.66000	RCASHFL1
RCASHFL2	.88000	.65000	.15000	.15000	.15000	3.08000	3.08000	RCASHFL2
RCASHFL3	1.09000	.77000	.59000	.59000	.59000	2.05000	2.05000	RCASHFL3
RCASHFL4	.15000	.15000	.80000	.80000	.80000	1.78000	4.00000	RCASHFL4
RCASHFL5	.15000	.15000	.83000	.83000	.83000	.15000	.15000	RCASHFL5
RCASHFL6	.92000	.	.15000	.15000	.15000	.	.	RCASHFL6
RSELLCRN	.	.	.	.	.	93.00000-	132.00000-	RSELLCRN
RSELLCOT	150.00000-	.	.	.	.	.	.	RSELLCOT
RSELLCTS	.12000-	.	.	.	.	.	.	RSELLCTS
RSELLGRS	.	15.00000-	.	.	.	.	.	RSELLGRS
RSELLWHT	.	.	15.00000-	14.00000-	.	.	.	RSELLWHT
RTRPAST1	.	.	.	.63000-	.	.	.	RTRPAST1
RTRPAST2	.	.	.	.	.85000-	.	.	RTRPAST2

Table 30. (continued)

	CORNSPP4	CORNSPP5	GRSOSPP0	GRSOSPP1	GRSOSPP2	GRSOSPP3	GRSOSPP4	
OBJF	11.42000-	12.90000-	3.39000-	4.13000-	5.61000-	7.09000-	8.20000-	OBJF
RTOTWATP	1.66670	2.00000	.16670	.33330	.66670	1.00000	1.25000	RTOTWATP
SPRACRES	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	SPRACRES
SPRKCORN	1.00000	1.00000	.	.	.	.	.	SPRKCORN
SPRKGRSO	.	.	1.00000	1.00000	1.00000	1.00000	1.00000	SPRKGRSO
RCWATP02	.25000	.25000	.	.	.	.	.	RCWATP02
RCWATP04	.	.	.16670	.16670	.16670	.16670	.16670	RCWATP04
RCWATP05	.25000	.25000	.	.	.	.16670	.25000	RCWATP05
RCWATP06	.66670	.66670	.	.16670	.33330	.33330	.33330	RCWATP06
RCWATP07	.50000	.66670	.	.	.16670	.33330	.50000	RCWATP07
RCWATP08	.	.16670	.	.	.	.	.	RCWATP08
RACRESPR	1.20000	1.20000	1.20000	1.20000	1.20000	1.20000	1.20000	RACRESPR
RACRETOT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACRETOT
RNATGSP2	.25000	.25000	.	.	.	.	.	RNATGSP2
RNATGSP3	.25000	.25000	.16670	.16670	.16670	.33330	.41670	RNATGSP3
RNATGSP4	1.16670	1.33330	.	.16670	.50000	.66670	.83330	RNATGSP4
RNATGSP5	.	.16670	.	.	.	.	.	RNATGSP5
RMLABRP1	.46000	.46000	.66000	.66000	.66000	.66000	.66000	RMLABRP1
RMLABRP2	1.36000	1.36000	.53000	.53000	.53000	.53000	.53000	RMLABRP2
RMLABRP3	.78000	.78000	.84000	.84000	.84000	.84000	.84000	RMLABRP3
RMLABRP4	.24000	.24000	.24000	.24000	.24000	.24000	.24000	RMLABRP4
RMLABRP5	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP5
RILABRP2	.14400	.14400	.	.	.	.	.	RILABRP2
RILABRP3	.14400	.14400	.09600	.09600	.09600	.19200	.24000	RILABRP3
RILABRP4	.67200	.76800	.	.09600	.28800	.38400	.48000	RILABRP4
RILABRP5	.	.09600	.	.	.	.	.	RILABRP5
RCORNSED	18.60000	22.00000	.	.	.	.	.	RCORNSED
RGRSOSED	.	.	3.75000	4.50000	6.00000	7.75000	9.25000	RGRSOSED
RCORNHRB	1.00000	1.00000	.	.	.	.	.	RCORNHRB
RGRSOHRB	.	.	1.00000	1.00000	1.00000	1.00000	1.00000	RGRSOHRB
RCRNINS3	1.00000	1.00000	.	.	.	.	.	RCRNINS3
RCRNINS4	1.00000	1.00000	.	.	.	.	.	RCRNINS4
RGRSINST	.	.	1.00000	1.00000	1.00000	1.00000	1.00000	RGRSINST
RNITROG2	170.00000	200.00000	50.00000	80.00000	120.00000	140.00000	160.00000	RNITROG2
RPHOSPHR	40.00000	40.00000	.	.	.	.	.	RPHOSPHR
RDIESEL1	1.60000	1.60000	2.13000	2.13000	2.13000	2.13000	2.13000	RDIESEL1
RDIESEL2	5.30000	5.30000	1.13000	1.13000	1.13000	1.13000	1.13000	RDIESEL2
RDIESEL3	2.30000	2.30000	2.38000	2.38000	2.38000	2.38000	2.38000	RDIESEL3
RGASOLN1	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN1
RGASOLN2	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN2
RGASOLN3	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN3
RGASOLN4	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN4
RGASOLN5	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN5
RCCCORNN	148.00000	156.00000	.	.	.	.	.	RCCCORNN
RCCGRSOI	.	.	21.00000	28.50000	50.00000	63.00000	67.50000	RCCGRSOI
RHAULCRN	148.00000	156.00000	.	.	.	.	.	RHAULCRN
RHAULGRS	.	.	21.00000	28.50000	50.00000	63.00000	67.50000	RHAULGRS
RDRYCORN	148.00000	156.00000	.	.	.	.	.	RDRYCORN
RIFXCEQ1	.	.	1.00000	1.00000	.	.	.	RIFXCEQ1
RIFXCEQ2	1.00000	1.00000	.	.	1.00000	1.00000	1.00000	RIFXCEQ2
RSPFXCST	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RSPFXCST
RCASHFL1	.66000	.66000	.71000	.71000	.71000	.71000	.71000	RCASHFL1

Table 30. (continued)

	CORNSPP4	CORNSPP5	GRSOSPP0	GRSOSPP1	GRSOSPP2	GRSOSPP3	GRSOSPP4	
RCASHFL2	3.08000	3.08000	.59000	.59000	.59000	.59000	.59000	RCASHFL2
RCASHFL3	2.05000	2.05000	1.64000	1.64000	1.64000	2.38000	2.75000	RCASHFL3
RCASHFL4	5.48000	6.22000	.30000	1.04000	2.52000	3.26000	4.00000	RCASHFL4
RCASHFL5	.15000	.89000	.15000	.15000	.15000	.15000	.15000	RCASHFL5
RSELLCRN	148.00000-	156.00000-	.	.	.	.	.	RSELLCRN
RSELLGRS	.	.	21.00000-	28.50000-	50.00000-	63.00000-	67.50000-	RSELLGRS

Table 30. (continued)

	WHETSPP0	WHETSPP1	WHETSPP2	WHETSPP3	WHETSPP4	WHETSPP5	WHETSPP6	
OBJF	5.64000-	6.38000-	7.12000-	7.86000-	8.60000-	9.34000-	10.08000-	OBJF
RTOTWATP	.25000	.41670	.58330	.75000	.91670	1.08330	1.25000	RTOTWATP
SPRACRES	1.00000	1.00000	1.00000	1.00000	1.00000	.	.	SPRACRES
SPRKWHET	1.00000	1.00000	1.00000	1.00000	1.00000	.	.	SPRKWHET
RCWATP02	.	.	.	.	.	.	.16670	RCWATP02
RCWATP03	.	.16670	.16670	.16670	.33330	.33330	.33330	RCWATP03
RCWATP04	.	.	.16670	.33330	.33330	.33330	.33330	RCWATP04
RCWATP08	.25000	.25000	.25000	.25000	.25000	.25000	.25000	RCWATP08
RCWATP10	.	.	.	.	.	.16670	.16670	RCWATP10
RACRESPR	1.20000	1.20000	1.20000	1.20000	1.20000	1.20000	1.20000	RACRESPR
RACRETOT	1.00000	1.00000	1.20000	1.00000	1.00000	1.00000	1.20000	RACRETOT
RNATGSP2	.	.16670	.16670	.16670	.33330	.33330	.50000	RNATGSP2
RNATGSP3	.	.	.16670	.33330	.33330	.33330	.33330	RNATGSP3
RNATGSP5	.25000	.25000	.25000	.25000	.25000	.25000	.25000	RNATGSP5
RNATGSP6	.	.	.	.	.	.16670	.16670	RNATGSP6
RMLABRP1	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP1
RMLABRP2	.24000	.24000	.24000	.24000	.24000	.24000	.24000	RMLABRP2
RMLABRP3	.58000	.58000	.58000	.58000	.58000	.58000	.58000	RMLABRP3
RMLABRP4	2.47000	2.47000	2.47000	2.47000	2.47000	2.47000	2.47000	RMLABRP4
RMLABRP5	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP5
RMLABRP6	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP6
RILABRP1	.	.	.	.	.	.	.28800	RILABRP1
RILABRP2	.	.09600	.09600	.09600	.19200	.19200	.19200	RILABRP2
RILABRP3	.	.	.09600	.19200	.19200	.19200	.	RILABRP3
RILABRP5	.14400	.14400	.14400	.14400	.14400	.14400	.14400	RILABRP5
RILABRP6	.	.	.	.	.	.09600	.09600	RILABRP6
RWHETINS	10.00000	15.00000	20.00000	25.00000	28.00000	31.00000	32.00000	RWHETINS
RWHETSED	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.25000	RWHETSED
RWHETHRA	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RWHETHRA
RWHTINST	1.00000	1.00000	1.00000	.	1.00000	1.00000	1.00000	RWHTINST
RNITROG4	40.00000	80.00000	120.00000	140.00000	160.00000	180.00000	200.00000	RNITROG4
RDIESEL3	1.13000	1.13000	1.13000	1.13000	1.13000	1.13000	1.13000	RDIESEL3
RDIESEL4	1.93000	1.93000	1.93000	1.93000	1.93000	1.93000	1.93000	RDIESEL4
RDIESEL5	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	RDIESEL5
RGASOLN1	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN1
RGASOLN2	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN2
RGASOLN3	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN3
RGASOLN4	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN4
RGASOLN5	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN5
RGASOLN6	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN6
RCCWHETI	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RCCWHETI
RHAULWHT	16.00000	25.50000	34.00000	41.00000	46.50000	51.00000	54.00000	RHAULWHT
RIFXCEQ1	1.00000	1.00000	.	.	.	.	.	RIFXCEQ1
RIFXCEQ2	.	.	1.00000	1.00000	1.00000	1.00000	1.00000	RIFXCEQ2
RSPFXCST	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RSPFXCST
RCASHFL1	.15000	.15000	.15000	.15000	.15000	.15000	.15000	RCASHFL1
RCASHFL2	.30000	1.04000	1.04000	1.04000	1.78000	1.78000	2.52000	RCASHFL2
RCASHFL3	.65000	.65000	1.39000	2.13000	2.13000	2.13000	2.13000	RCASHFL3
RCASHFL4	3.13000	3.13000	3.13000	3.13000	3.13000	3.13000	3.13000	RCASHFL4
RCASHFL5	1.26000	1.26000	1.26000	1.26000	1.26000	1.26000	1.26000	RCASHFL5
RCASHFL6	.15000	.15000	.15000	.15000	.15000	.89000	.83000	RCASHFL6
RSELLWHT	16.00000-	25.50000-	34.00000-	41.00000-	46.50000-	51.00000-	54.00000-	RSELLWHT

Table 30. (continued)

	WHTGSPP0	WHTGSPP1	WHTGSPP2	WHTGSPP3	WHTGSPP4	WHTGSPP5	WHTGSPP6	
OBJF	5.64000-	6.38000-	7.12000-	7.86000-	8.60000-	9.34000-	10.08000-	OBJF
RTOTWATP	.25000	.41670	.58330	.75000	.91670	1.08330	1.25000	RTOTWATP
SPRACRES	1.00000	1.00000	1.00000	1.00000	1.00000	.	.	SPRACRES
SPRKWHGR	1.00000	1.00000	1.00000	1.00000	1.00000	.	.	SPRKWHGR
RCWATP02	.	.	.	.	.	.16670	.16670	RCWATP02
RCWATP03	.	.16670	.16670	.16670	.16670	.16670	.16670	RCWATP03
RCWATP04	.	.	.16670	.16670	.33330	.33330	.33330	RCWATP04
RCWATP07	.25000	.25000	.25000	.25000	.25000	.25000	.25000	RCWATP07
RCWATP09	.	.	.	.16670	.16670	.16670	.16670	RCWATP09
RCWATP10	.	.	.	.	.	.	.16670	RCWATP10
RACRESPR	1.20000	1.20000	1.20000	1.20000	1.20000	1.20000	1.20000	RACRESPR
RACRETOT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACRETOT
RNATGSP2	.	.16670	.16670	.16670	.16670	.33330	.33330	RNATGSP2
RNATGSP3	.	.	.16670	.16670	.33330	.33330	.33330	RNATGSP3
RNATGSP4	.25000	.25000	.25000	.25000	.25000	.25000	.25000	RNATGSP4
RNATGSP5	.	.	.	.16670	.16670	.16670	.16670	RNATGSP5
RNATGSP6	.	.	.	.	.	.	.16670	RNATGSP6
RMLABRP1	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP1
RMLABRP2	.24000	.24000	.24000	.24000	.24000	.24000	.24000	RMLABRP2
RMLABRP3	.58000	.58000	.58000	.58000	.58000	.58000	.58000	RMLABRP3
RMLABRP4	2.47000	2.47000	2.47000	2.47000	2.47000	2.47000	2.47000	RMLABRP4
RMLABRP5	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP5
RMLABRP6	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP6
RILABRP2	.	.09600	.09600	.09600	.09600	.19200	.19200	RILABRP2
RILABRP3	.	.	.09600	.09600	.19200	.19200	.19200	RILABRP3
RILABRP4	.14400	.14400	.14400	.14400	.14400	.14400	.14400	RILABRP4
RILABRP5	.	.	.	.09600	.09600	.09600	.09600	RILABRP5
RILABRP6	.	.	.	.	.	.	.09600	RILABRP6
RWHETINS	9.00000	14.00000	18.00000	22.00000	25.00000	28.00000	29.00000	RWHETINS
RWHETSED	1.00000	1.50000	1.50000	1.50000	1.50000	1.50000	1.50000	RWHETSED
RWHETHRB	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RWHETHRB
RWHTINST	.50000	.50000	.50000	.50000	.50000	.50000	.50000	RWHTINST
RNITROG4	40.00000	80.00000	120.00000	140.00000	160.00000	180.00000	200.00000	RNITROG4
RDIESEL3	1.13000	1.13000	1.13000	1.13000	1.13000	1.13000	1.13000	RDIESEL3
RDIESEL4	1.93000	1.93000	1.93000	1.93000	1.93000	1.93000	1.93000	RDIESEL4
RDIESEL5	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	RDIESEL5
RGASOLN1	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN1
RGASOLN2	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN2
RGASOLN3	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN3
RGASOLN4	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN4
RGASOLN5	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN5
RGASOLN6	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN6
RCCWHETI	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RCCWHETI
RHAULWHT	14.50000	23.00000	30.50000	37.00000	42.00000	46.00000	48.50000	RHAULWHT
RIFXCEQ1	1.00000	1.00000	.	.	.	.	.	RIFXCEQ1
RIFXCEQ2	.	.	1.00000	1.00000	1.00000	1.00000	1.00000	RIFXCEQ2
RSPFXCST	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RSPFXCST
RCASHFL1	.15000	.15000	.15000	.15000	.15000	.15000	.15000	RCASHFL1
RCASHFL2	.30000	1.04000	1.04000	1.04000	1.04000	1.78000	1.78000	RCASHFL2
RCASHFL3	.65000	.65000	1.39000	2.13000	2.13000	2.11000	2.11000	RCASHFL3
RCASHFL4	4.24000	4.24000	4.24000	4.24000	4.24000	4.24000	4.24000	RCASHFL4
RCASHFL5	.15000	.15000	.15000	.15000	.89000	.89000	.89000	RCASHFL5

Table 30. (continued)

	WHTGSPP0	WHTGSPP1	WHTGSPP2	WHTGSPP3	WHTGSPP4	WHTGSPP5	WHTGSPP6	
RCASHFL6	.15000	.15000	.15000	.15000	.15000	.15000	.89000	RCASHFL6
RSELLWHT	14.50000-	23.00000-	30.50000-	37.00000-	42.00000-	46.00000-	48.50000-	RSELLWHT
RTRPAST1	.76000-	.76000-	.76000-	1.51000-	1.51000-	1.51000-	2.84000-	RTRPAST1

Table 30. (continued)

	WTGOSPP2	WTGOSPP3	WTGOSPP4	WTGOSPP5	CORNFPP2	CORNFPP3	CORNFPP4	
OBJF	7.12000-	7.86000-	8.60000-	9.34000-	8.28000-	9.16000-	10.04000-	OBJF
RTOTWATP	.58330	.75000	.91670	1.08330	1.25000	1.58330	1.91670	RTOTWATP
SPRACRES	1.00000	1.00000	1.00000	.	.	.	.	SPRACRES
SPRKWHGR	1.00000	1.00000	1.00000	.	.	.	.	SPRKWHGR
FURACRES	.	.	.	.	1.00000	1.00000	1.00000	FURACRES
FURRCORN	.	.	.	.	1.00000	1.00000	1.00000	FURRCORN
RCWATP02	.16670	.16670	.16670	.16670	.58330	.58330	.58330	RCWATP02
RCWATP03	.	.16670	.16670	.33330	.	.	.	RCWATP03
RCWATP05	.	.	.	.	.33330	.33330	.33330	RCWATP05
RCWATP06	.	.	.	.	.33330	.66670	.66670	RCWATP06
RCWATP07	.25000	.25000	.25000	.25000	.	.	.33330	RCWATP07
RCWATP09	.16670	.16670	.16670	.16670	.	.	.	RCWATP09
RCWATP10	.	.	.16670	.16670	.	.	.	RCWATP10
RACRESPR	1.20000	1.20000	1.20000	1.20000	.	.	.	RACRESPR
RACREFUR	.	.	.	.	1.00000	1.00000	1.00000	RACREFUR
RACRETOT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACRETOT
RNATGSP2	.16670	.33330	.33330	.50000	.	.	.	RNATGSP2
RNATGSP4	.25000	.25000	.25000	.25000	.	.	.	RNATGSP4
RNATGSP5	.16670	.16670	.16670	.16670	.	.	.	RNATGSP5
RNATGSP6	.	.	.16670	.16670	.	.	.	RNATGSP6
RNATGFR2	.	.	.	.	.58330	.58330	.58330	RNATGFR2
RNATGFR3	.	.	.	.	.33330	.33330	.33330	RNATGFR3
RNATGFR4	.	.	.	.	.33330	.66670	1.00000	RNATGFR4
RMLABRP1	.12000	.12000	.12000	.12000	.81000	.31000	.81000	RMLABRP1
RMLABRP2	.24000	.24000	.24000	.24000	1.98000	1.98000	1.98000	RMLABRP2
RMLABRP3	.58000	.58000	.58000	.58000	.44000	.44000	.44000	RMLABRP3
RMLABRP4	2.47000	2.47000	2.47000	2.47000	.24000	.24000	.24000	RMLABRP4
RMLABRP5	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP5
RMLABRP6	.12000	.12000	.12000	.12000	1.07000	1.07000	1.07000	RMLABRP6
RILABRP2	.09600	.19200	.19200	.28800	.86100	.86100	.86100	RILABRP2
RILABRP3	.	.	.	.	.49200	.49200	.49200	RILABRP3
RILABRP4	.14400	.14400	.14400	.14400	.49200	.98400	1.47600	RILABRP4
RILABRP5	.09600	.09600	.09600	.09600	.	.	.	RILABRP5
RILABRP6	.	.	.09600	.09600	.	.	.	RILABRP6
RCORNSED	.	.	.	.	16.00000	17.30000	18.60000	RCORNSED
RWHETSFD	1.50000	1.50000	1.50000	1.50000	.	.	.	RWHETSFD
RCORNHRB	.	.	.	.	1.00000	1.00000	1.00000	RCORNHRB
RCRNINS3	.	.	.	.	1.00000	1.00000	1.00000	RCRNINS3
RCRNINS4	.	.	.	.	1.00000	1.00000	1.00000	RCRNINS4
RWHTINST	.50000	.50000	.50000	.50000	.	.	.	RWHTINST
RNITPOG2	.	.	.	.	120.00000	145.00000	170.00000	RNITPOG2
RPHOSPHR	.	.	.	.	.	.	40.00000	RPHOSPHR
RDIESEL1	.	.	.	.	2.28000	2.29000	2.28000	RDIESEL1
RDIESEL2	.	.	.	.	6.93000	6.93000	6.93000	RDIESEL2
RDIESEL3	1.13000	1.13000	1.13000	1.13000	.80000	.80000	.80000	RDIESEL3
RDIESEL4	1.93000	1.93000	1.93000	1.93000	.	.	.	RDIESEL4
RDIESEL5	2.60000	2.60000	2.60000	2.60000	.	.	.	RDIESEL5
RDIESEL6	.	.	.	.	2.95000	2.95000	2.95000	RDIESEL6
RGASOLN1	.55000	.55000	.55000	.55000	1.10000	1.10000	1.10000	RGASOLN1
RGASOLN2	.55000	.55000	.55000	.55000	1.10000	1.10000	1.10000	RGASOLN2
RGASCLN3	1.10000	1.10000	1.10000	1.10000	1.68000	1.68000	1.68000	RGASCLN3
RGASOLN4	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.13000	RGASOLN4

Table 30. (continued)

	WTGOSPP2	WTGOSPP3	WTGOSPP4	WTGOSPP5	CORNFPP2	CORNFPP3	CORNFPP4	
RGASOLN5	.55000	.55000	.55000	.55000	1.10000	1.10000	1.10000	RGASOLN5
RGASOLN6	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN6
RCCCORNN	.	.	.	.	81.00000	106.00000	126.00000	RCCCORNN
RHAULCRN	.	.	.	.	81.00000	106.00000	126.00000	RHAULCRN
RDRYCORN	.	.	.	.	81.00000	106.00000	126.00000	RDRYCORN
RIFXCEQ2	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RIFXCEQ2
RSPFXCST	1.00000	1.00000	1.00000	1.00000	.	.	.	RSPFXCST
RFRFXCST	.	.	.	.	1.00000	1.00000	1.00000	RFRFXCST
RCASHFL1	.15000	.15000	.15000	.15000	.89000	.89000	.89000	RCASHFL1
RCASHFL2	1.04000	1.78000	1.78000	2.52000	3.61000	3.61000	3.61000	RCASHFL2
RCASHFL3	.65000	.65000	.65000	.65000	1.39000	1.39000	1.39000	RCASHFL3
RCASHFL4	4.24000	4.24000	4.24000	4.24000	1.18000	2.06000	2.94000	RCASHFL4
RCASHFL5	.89000	.89000	.89000	.89000	.15000	.15000	.15000	RCASHFL5
RCASHFL6	.15000	.15000	.89000	.89000	1.06000	1.06000	1.06000	RCASHFL6
RSELLCRN	.	.	.	.	81.00000-	106.00000-	126.00000-	RSELLCRN
RTRPAST2	2.04000-	3.06000-	4.07000-	4.58000-	.	.	.	RTRPAST2

Table 30. (continued)

	CORNFPP5	CORNFPP6	COTNFPP0	COTNFPP1	CCTNFPP2	COTNFPP3	GRSOFPP0	
OBJF	10.92000-	11.90000-	6.85000-	7.73000-	8.61000-	9.49000-	6.17000-	OBJF
RTOTWATP	2.25000	2.58330	.58330	.91670	1.25000	1.58330	.58330	RTOTWATP
FURACRES	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	FURACRES
FURRCORN	1.00000	1.00000	.	.	.	.	.	FURRCORN
FURRCOTN	.	.	1.00000	1.00000	1.00000	1.00000	.	FURRCOTN
FURRGRSO	.	.	.	.	.	.	1.00000	FURRGRSO
RCWATP02	.58330	.58330	.	.	.	.	.	RCWATP02
RCWATP03	.	.	.58330	.58330	.58330	.58330	.58330	RCWATP03
RCWATP05	.33330	.33330	.	.33330	.33330	.33330	.	RCWATP05
RCWATP06	.66670	.66670	.	.	.33330	.33330	.	RCWATP06
RCWATP07	.66670	.66670	.	.	.	.33330	.	RCWATP07
RCWATP08	.	.33330	.	.	.	.	.	RCWATP08
RACREFUR	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACREFUR
RACRETOT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACRETOT
RNATGFR2	.58330	.58330	.58330	.58330	.58330	.58330	.58330	RNATGFR2
RNATGFR3	.33330	.33330	.	.33330	.33330	.33330	.	RNATGFR3
RNATGFR4	1.33330	1.33330	.	.	.33330	.66670	.	RNATGFR4
RNATGFR5	.	.33330	.	.	.	.	.	RNATGFR5
RMLABRP1	.81000	.81000	.65000	.65000	.65000	.65000	.69000	RMLABRP1
RMLABRP2	1.98000	1.98000	.94000	.94000	.94000	.94000	1.34000	RMLABRP2
RMLABRP3	.44000	.44000	1.32000	1.32000	1.32000	1.32000	1.23000	RMLABRP3
RMLABRP4	.24000	.24000	.24000	.24000	.24000	.24000	.24000	RMLABRP4
RMLABRP5	.12000	.12000	.24000	.24000	.24000	.24000	.12000	RMLABRP5
RMLABRP6	1.07000	1.07000	1.23000	1.23000	1.23000	1.23000	.66000	RMLABRP6
RILABRP2	.86100	.86100	.86100	.86100	.86100	.86100	.86100	RILABRP2
RILABRP3	.49200	.49200	.	.49200	.49200	.49200	.	RILABRP3
RILABRP4	1.96800	1.96800	.	.	.49200	.98400	.	RILABRP4
RILABRP5	.	.49200	.	.	.	.	.	RILABRP5
RHLABRP4	.	.	2.50000	2.75000	3.00000	3.25000	.	RHLABRP4
RCOTNINS	.	.	110.00000	145.00000	170.00000	180.00000	.	RCOTNINS
RCORNSED	22.00000	24.00000	.	.	.	.	.	RCORNSED
RCOTNSED	.	.	27.50000	27.50000	27.50000	27.50000	.	RCOTNSED
RGRSOSED	.	.	.	.	.	.	5.40000	RGRSOSED
RCORNHRB	1.00000	1.00000	.	.	.	.	.	RCORNHRB
RCOTIHRB	.	.	1.00000	1.00000	1.00000	1.00000	.	RCOTIHRB
RGRSCHRB	.	.	.	.	.	.	1.00000	RGRSCHRB
RCRNINS3	1.00000	1.00000	.	.	.	.	.	RCRNINS3
RCRNINS4	1.00000	1.00000	.	.	.	.	.	RCRNINS4
RCOTINST	.	.	1.00000	1.00000	1.00000	1.00000	.	RCOTINST
RGRSINST	.	.	.	.	.	.	1.00000	RGRSINST
RNITROG2	200.00000	230.00000	.	.	40.00000	40.00000	40.00000	RNITROG2
RPHOSPHR	40.00000	40.00000	.	.	.	.	.	RPHOSPHR
RDIESEL1	2.28000	2.28000	1.75000	1.75000	1.75000	1.75000	.	RDIESEL1
RDIESEL2	6.93000	6.93000	2.93000	2.93000	2.93000	2.93000	4.45000	RDIESEL2
RDIESEL3	.80000	.80000	3.35000	3.35000	3.35000	3.35000	3.95000	RDIESEL3
RDIESEL6	2.95000	2.95000	5.03000	5.03000	5.03000	5.03100	2.13000	RDIESEL6
RGASOLN1	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	.55000	RGASOLN1
RGASOLN2	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN2
RGASOLN3	1.68000	1.68000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN3
RGASOLN4	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN4
RGASOLN5	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	.55000	RGASOLN5
RGASOLN6	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN6

Table 30. (continued)

	CORNFPP5	CORNFPP6	COTNFPP0	COTNFPP1	COTNFPP2	CCTNFPP3	GRSOFPP0	
RCCCORNN	141.00000	151.00000	.	.	.	.	.	RCCCORNN
RCCGRSOI	.	.	.	.	.	.	21.00000	RCCGRSOI
RCSHCOTN	.	.	3.50000	4.25000	5.00000	5.25000	.	RCSHCOTN
RGINCOTN	.	.	3.50000	4.25000	5.00000	5.25000	.	RGINCOTN
RHAULCRN	141.00000	151.00000	.	.	.	.	.	RHAULCRN
RHAULGRS	.	.	.	.	.	.	21.00000	RHAULGRS
RDRYCURN	141.00000	151.00000	.	.	.	.	.	RDRYCURN
RIFXCEQ1	.	.	1.00000	1.00000	.	.	1.00000	RIFXCEQ1
RIFXCEQ2	1.00000	1.00000	.	.	1.00000	1.00000	.	RIFXCEQ2
RFRFXCST	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RFRFXCST
RCASHFL1	.89000	.89000	.82000	.82000	.82000	.82000	.74000	RCASHFL1
RCASHFL2	3.61000	3.61000	2.65000	2.65000	2.65000	2.65000	2.98000	RCASHFL2
RCASHFL3	1.39000	1.39000	1.11000	1.99000	1.99000	1.99000	1.31000	RCASHFL3
RCASHFL4	3.82000	3.82000	.30000	.30000	1.18000	2.06000	.30000	RCASHFL4
RCASHFL5	.15000	1.03000	.30000	.30000	.30000	.30000	.15000	RCASHFL5
RCASHFL6	1.06000	1.06000	1.67000	1.67000	1.67000	1.67000	.69000	RCASHFL6
RSELLCPN	141.00000-	151.00000-	.	.	.	.	.	RSELLCPN
RSELLCOT	.	.	350.00000-	425.00000-	500.00000-	525.00000-	.	RSELLCOT
RSELLCTS	.	.	.12000-	.34000-	.40000-	.42000-	.	RSELLCTS
RSELLGRS	.	.	.	.	.	.	21.00000-	RSELLGRS

Table 30. (continued)

	GRSOFPP1	GRSOFPP2	GRSOFPP3	GRSOFPP4	SOYRFPP2	SOYRFPP3	SOYRFPP4	
DBJF	7.05000-	7.93000-	8.18000-	9.69000-	8.95000-	9.83000-	10.71000-	DBJF
RTOTWATP	.91670	1.25000	1.58330	1.91670	1.25000	1.58330	1.91670	RTOTWATP
FURACRES	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	FURACRES
FURRGRSO	1.00000	1.00000	1.00000	1.00000	.	.	.	FURRGRSO
FURRSOYB	.	.	.	.	1.00000	1.00000	1.00000	FURRSOYB
RCWATP02	.	.	.	.	.58330	.58330	.58330	RCWATP02
RCWATP03	.58330	.58330	.58330	.58330	.	.	.	RCWATP03
RCWATP05	.	.	.	.33330	.	.	.	RCWATP05
RCWATP06	.33330	.33330	.33330	.33330	.33330	.33330	.66670	RCWATP06
RCWATP07	.	.33330	.66670	.66670	.33330	.66670	.66670	RCWATP07
RACREFUR	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACREFUR
RACRFTOT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACRFTOT
RNATGFR2	.58330	.58330	.58330	.58330	.58330	.58330	.58330	RNATGFR2
RNATGFR3	.	.	.	.33330	.	.	.	RNATGFR3
RNATGFR4	.33330	.66670	1.00000	1.00000	.66670	1.00000	1.33330	RNATGFR4
RMLABRP1	.69000	.69000	.63000	.69000	.53000	.53000	.53000	RMLABRP1
RMLABRP2	1.34000	1.34000	1.34000	1.34000	2.20000	2.20000	2.20000	RMLABRP2
RMLABRP3	1.23000	1.23000	1.23000	1.23000	.78000	.78000	.78000	RMLABRP3
RMLABRP4	.24000	.24000	.24000	.24000	.42000	.42000	.42000	RMLABRP4
RMLABRP5	.12000	.12000	.12000	.12000	.24000	.24000	.24000	RMLABRP5
RMLABRP6	.66000	.66000	.66000	.66000	1.06000	1.06000	1.06000	RMLABRP6
RILABRP2	.86100	.86100	.86100	.86100	.86100	.86100	.86100	RILABRP2
RILABRP3	.	.98400	.	.49200	.	.	.	RILABRP3
RILABRP4	.49200	.	1.47600	1.47600	.98400	1.47600	1.97000	RILABRP4
RGRSOSED	7.00000	8.50000	10.00000	11.60000	.	.	.	RGRSOSED
RSOYBSED	.	.	.	.	60.00000	60.00000	60.00000	RSOYBSED
RGRSOHRB	1.00000	1.00000	1.00000	1.00000	.	.	.	RGRSOHRB
RGRSINST	1.00000	1.00000	1.00000	1.00000	.	.	.	RGRSINST
RNITROG2	80.00000	120.00000	140.00000	160.00000	.	.	.	RNITROG2
RDIESEL1	2.28000	2.28000	2.28000	2.28000	1.13000	1.13000	1.13000	RDIESEL1
RDIESEL2	4.45000	4.45000	4.45000	4.45000	7.83000	7.83000	7.83000	RDIESEL2
RDIESEL3	1.95000	3.95000	3.95000	3.95000	2.15000	2.15000	2.15000	RDIESEL3
RDIESEL4	.	.	.	.	.70000	.70000	.70000	RDIESEL4
RDIESEL6	2.13000	2.13000	2.13000	2.13000	3.25000	3.25000	3.25000	RDIESEL6
RGASOLN1	.55000	.55000	.55000	.55000	1.10000	1.10000	1.10000	RGASOLN1
RGASOLN2	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN2
RGASOLN3	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN3
RGASOLN4	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN4
RGASOLN5	.55000	.55000	.55000	.55000	1.10000	1.10000	1.10000	RGASOLN5
RGASCLN6	.55000	.55000	.55000	.55000	1.10000	1.10000	1.10000	RGASCLN6
RCCGRSO1	40.00000	54.00000	63.00000	67.00000	.	.	.	RCCGRSO1
RCCSOYBN	.	.	.	.	1.00000	1.00000	1.00000	RCCSOYBN
RHAULGRS	40.00000	54.00000	63.00000	67.00000	.	.	.	RHAULGRS
RHAULSOY	.	.	.	.	37.00000	43.00000	49.00000	RHAULSOY
RIFXCE01	1.00000	.	.	.	.	.	.	RIFXCE01
RIFXCE02	.	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RIFXCE02
RFRFXCST	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RFRFXCST
RCASHFL1	.74000	.74000	.74000	.74000	.59000	.59000	.59000	RCASHFL1
RCASHFL2	2.98000	2.98000	2.98000	2.98000	3.83000	3.83000	3.83000	RCASHFL2
RCASHFL3	1.31000	1.31000	1.31000	2.19000	.85000	.85000	.85000	RCASHFL3
RCASHFL4	1.18000	2.06000	2.94000	2.94000	2.24000	3.12000	4.00000	RCASHFL4
RCASHFL5	.15000	.15000	.15000	.15000	.30000	.30000	.30000	RCASHFL5

Table 30. (continued)

	GRSOFPP1	GRSOFPP2	GRSOFPP3	GRSOFPP4	SOYBFPP2	SOYBFPP3	SOYBFPP4	
RCASHFL6	.69000	.69000	.69000	.69000	1.14000	1.14000	1.14000	RCASHFL6
RSELLGRS	40.00000-	54.00000-	63.00000-	67.00000-	.	.	.	RSELLGRS
RSELLSOY	.	.	.	.	37.00000-	43.00000-	49.00000-	RSELLSOY

Table 30. (continued)

	WHETFPP0	WHETFPP1	WHETFPP2	WHETFPP3	WHETFPP4	WHETFPP5	WHTGFPP0	
OBJF	5.16000-	6.04000-	6.92000-	7.80000-	8.68000-	9.56000-	5.16000-	OBJF
RTOTWATP	.41670	.75000	1.08330	1.41670	1.75000	2.08330	.41670	RTOTWATP
FURACRES	1.00000	1.00000	1.00000	1.00000	.	.	1.00000	FURACRES
FURRWHET	1.00000	1.00000	1.00000	1.00000	.	.	.	FURRWHET
FURRWHGR	.	.	.	.	.	.	1.00000	FURRWHGR
RCWATP02	.	.	.	.	.33330	.33330	.	RCWATP02
RCWATP03	.	.33330	.33330	.33330	.33330	.33330	.	RCWATP03
RCWATP04	.	.	.33300	.66670	.66670	.66670	.	RCWATP04
RCWATP07	.	.	.	.	.	.	.41670	RCWATP07
RCWATP08	.41670	.41670	.41670	.41670	.41670	.41670	.	RCWATP08
RCWATP10	.	.	.	.	.	.33330	.	RCWATP10
RACREFUP	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACREFUP
RACRETOT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACRETOT
RNATGFR2	.	.33330	.33330	.33330	.66670	.66670	.	RNATGFR2
RNATGFR3	.	.	.33330	.66670	.66670	.66670	.	RNATGFR3
RNATGFR4	.	.	.	.	.	.	.41670	RNATGFR4
RNATGFR5	.41670	.41670	.41670	.41670	.41670	.41670	.	RNATGFR5
RNATGFR6	.	.	.	.	.	.33330	.	RNATGFR6
RMLABRP1	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP1
RMLABRP2	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP2
RMLABRP3	.53000	.53000	.53000	.53000	.53000	.53000	.53000	RMLABRP3
RMLABRP4	2.77000	2.77000	2.77000	2.77000	2.77000	2.77000	2.77000	RMLABRP4
RMLABRP5	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP5
RMLABRP6	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP6
RILABRP2	.	.49200	.49200	.49200	.98400	.98400	.	RILABRP2
RILABRP3	.	.	.49200	.98400	.98400	.98400	.	RILABRP3
RILABRP4	.	.	.	.	.	.	.61500	RILABRP4
RILABRP5	.61500	.61500	.61500	.61500	.61500	.61500	.	RILABRP5
RILABRP6	.	.	.	.	.	.49200	.	RILABRP6
RWHETINS	11.00000	19.00000	26.00000	31.00000	34.00000	37.00000	10.00000	RWHETINS
RWHETSED	1.00000	1.00000	1.00000	1.25000	1.25000	1.25000	1.00000	RWHETSED
RWHETHRB	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RWHETHRB
RWHTINST	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	.50000	RWHTINST
RNITROG4	40.00000	80.00000	100.00000	120.00000	140.00000	150.00000	40.00000	RNITROG4
RDIESEL1	.68000	.68000	.58000	.68000	.68000	.68000	.68000	RDIESEL1
RDIESEL2	.68000	.68000	.68000	.68000	.68000	.68000	.68000	RDIESEL2
RDIESEL3	1.36000	1.36000	1.36000	1.36000	1.36000	1.36000	1.36000	RDIESEL3
RDIESEL4	1.36000	1.36000	1.36000	1.36000	1.36000	1.36000	1.36000	RDIESEL4
RDIESEL5	.68000	.68000	.68000	.68000	.68000	.63000	.68000	RDIESEL5
RDIESEL6	.68000	.68000	.68000	.68000	.68000	.60000	.68000	RDIESEL6
RGASOLN1	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN1
RGASOLN2	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN2
RGASOLN3	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN3
RGASOLN4	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN4
RGASOLN5	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN5
RGASOLN6	.55000	.55000	.53000	.55000	.55000	.55000	.55000	RGASOLN6
RCCWHETI	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RCCWHETI
RHAULWHT	19.00000	31.00000	43.00000	51.00000	56.00000	62.00000	17.00000	RHAULWHT
RIFXCEQ1	1.00000	1.00000	.	.	.	.	1.00000	RIFXCEQ1
RIFXCEQ2	.	.	1.00000	1.00000	1.00000	1.00000	.	RIFXCEQ2
RFRFXCST	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RFRFXCST
RCASHFL1	.15000	.15000	.15000	.15000	.15000	.15000	.15000	RCASHFL1

Table 30. (continued)

	WHETFPP0	WHETFPP1	WHETFPP2	WHETFPP3	WHETFPP4	WHETFPP5	WHTGFPP0	
RCASHFL2	.15000	.15000	1.03000	1.03000	1.91000	1.91000	.15000	RCASHFL2
RCASHFL3	.59000	1.47000	1.47000	2.35000	2.35000	2.35000	.59000	RCASHFL3
RCASHFL4	2.87000	2.87000	2.87000	2.87000	2.87000	2.87000	3.97000	RCASHFL4
RCASHFL5	1.25000	1.25000	1.25000	1.25000	1.25000	1.25000	.15000	RCASHFL5
RCASHFL6	.15000	15.00000	.15000	.15000	.15000	1.03000	.15000	RCASHFL6
RSELLWHT	19.00000-	31.00000-	43.00000-	51.00000-	56.00000-	62.00000-	17.00000-	RSELLWHT
RTRPAST1	.	.	.	.	.	.	.76000-	RTRPAST1

Table 30. (continued)

	WHTGFPP1	WHTGFPP2	WHTGFPP3	WHTGFPP4	WHTGFPP5	WTGOFPP2	WTGOFPP3	
OBJF	6.04000-	6.92000-	7.80000-	8.68000-	9.56000-	6.92000-	7.80000-	OBJF
RTOTWATP	.75000	1.08330	1.41670	1.75000	2.08330	1.08330	1.41670	RTOTWATP
FURACRES	1.00000	1.00000	1.00000	.	.	1.00000	1.00000	FURACRES
FURRWHGR	1.00000	1.00000	1.00000	.	.	1.00000	1.00000	FURRWHGR
RCWATP02	.	.	.	.	.33330	.33330	.33330	RCWATP02
RCWATP03	.33330	.33330	.33330	.33330	.33330	.	.33330	RCWATP03
RCWATP04	.	.33330	.33330	.66670	.66670	.	.	RCWATP04
RCWATP07	.41670	.41670	.41670	.41670	.41670	.41670	.41670	RCWATP07
RCWATP09	.	.	.33330	.33330	.33330	.33330	.33330	RCWATP09
RACREFUR	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACREFUR
RACRETOT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RACRETOT
RNATGFR2	.33330	.33330	.33330	.33330	.66670	.33330	.66670	RNATGFR2
RNATGFR3	.	.33330	.33330	.66670	.66670	.	.	RNATGFR3
RNATGFR4	.41670	.41670	.41670	.41670	.41670	.41670	.41670	RNATGFR4
RNATGFR5	.	.	.33330	.33330	.33330	.33330	.33330	RNATGFR5
RMLABRP1	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP1
RMLABRP2	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP2
RMLABRP3	.53000	.53000	.53000	.53000	.53000	.53000	.53000	RMLABRP3
RMLABRP4	2.77000	2.77000	2.77000	2.77000	2.77000	2.77000	2.77000	RMLABRP4
RMLABRP5	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP5
RMLABRP6	.12000	.12000	.12000	.12000	.12000	.12000	.12000	RMLABRP6
RILABRP2	.49200	.49200	.49200	.49200	.98400	.49200	.98400	RILABRP2
RILABRP3	.	.49200	.49200	.98400	.98400	.	.	RILABRP3
RILABRP4	.61500	.61500	.61500	.61500	.61500	.61500	.61500	RILABRP4
RILABRP5	.	.	.49200	.49200	.49200	.49200	.49200	RILABRP5
RWHETINS	17.00000	25.00000	29.00000	32.00000	34.00000	.	.	RWHETINS
RWHETSED	1.00000	1.50000	1.50000	1.50000	1.50000	1.50000	1.50000	RWHETSED
RWHETHRB	1.00000	1.00000	1.00000	1.00000	1.00000	.	.	RWHETHRB
RWHTINST	.50000	.50000	.50000	.50000	.50000	.50000	.50000	RWHTINST
RNITROG4	80.00000	100.00000	120.00000	140.00000	150.00000	100.00000	120.00000	RNITROG4
RDIESEL1.	.68000	.68000	.68000	.68000	.68000	.68000	.68000	RDIESEL1.
RDIESEL2	.68000	.68000	.68000	.68000	.68000	.68000	.68000	RDIESEL2
RDIESEL3	1.36000	1.36000	1.36000	1.36000	1.36000	1.36000	1.36000	RDIESEL3
RDIESEL4	1.36000	1.36000	1.36000	1.36000	1.36000	1.36000	1.36000	RDIESEL4
RDIESEL5	.68000	.68000	.68000	.68000	.68000	.68000	.68000	RDIESEL5
RDIESEL6	.68000	.68000	.68000	.68000	.68000	.68000	.68000	RDIESEL6
RGASOLN1	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN1
RGASOLN2	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN2
RGASOLN3	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN3
RGASOLN4	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	1.10000	RGASOLN4
PGASOLN5	.55000	.55000	.55000	.55000	.55000	.55000	.55000	PGASOLN5
RGASOLN6	.55000	.55000	.55000	.55000	.55000	.55000	.55000	RGASOLN6
RCCWHET1	1.00000	1.00000	1.00000	1.00000	1.00000	.	.	RCCWHET1
RHAULWHT	28.00000	39.00000	46.00000	50.00000	56.00000	.	.	RHAULWHT
RIFXCEQ1	1.00000	.	.	.	.	.	.	RIFXCEQ1
RIFXCEQ2	.	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	RIFXCEQ2
RFRFXCST	1.00000	1.03000	1.00000	1.00000	1.00000	1.00000	1.00000	RFRFXCST
RCASHFL1	.15000	.15000	.15000	.15000	.15000	.15000	.15000	RCASHFL1
RCASHFL2	1.03000	1.03000	1.03000	1.03000	1.91000	1.03000	1.91000	RCASHFL2
RCASHFL3	.59000	1.47000	1.47000	2.35000	2.35000	.59000	.59000	RCASHFL3
RCASHFL4	3.97000	3.97000	3.97000	3.97000	3.97000	3.97000	3.97000	RCASHFL4
RCASHFL5	.15000	.15000	1.03000	1.03000	1.03000	1.03000	1.03000	RCASHFL5

Table 30. (continued)

	WHTGFPP1	WHTGFPP2	WHTGFPP3	WHTGFPP4	WHTGFPP5	WTGOFPP2	WTGOFPP3	
RCASHFL6	.15000	.15000	.15000	.15000	.15000	.15000	.15000	RCASHFL6
RSELL.WHT	28.00000-	39.00000-	46.00000-	50.00000-	56.00000-	.	.	RSELL.WHT
RTRPAST1	.76000-	.76000-	1.51000-	1.51000-	2.84000-	.	.	RTRPAST1
RTRPAST2	.	.	.	.	.	3.06000-	4.07000-	RTRPAST2

Table 30. (continued)

	WTGDFPP4	GRAZSTK1	GRAZSTK2	BUYSTOKR	NATGSPR1	NATGSPR2	NATGSPR3	
OBJF	8.68000-	33.40000-	34.84000-	.64000-	1.50000-	1.50000-	1.50000-	OBJF
RTOTWATP	1.75000	.	.	.	.	.	.	RTOTWATP
FEEDERSL	.	1.00000	.	.	.	.	.	FEEDERSL
FEEDERSH	.	.	1.00000	.	.	.	.	FEEDERSH
RCWATP02	.33330	.	.	.	.	.	.	RCWATP02
RCWATP03	.33330	.	.	.	.	.	.	RCWATP03
RCWATP07	.41670	.	.	.	.	.	.	RCWATP07
RCWATP09	.33330	.	.	.	.	.	.	RCWATP09
RCWATP10	.33330	.	.	.	.	.	.	RCWATP10
RACREFUR	1.00000	.	.	.	.	.	.	RACREFUR
RACRETOT	1.00000	.	.	.	.	.	.	RACRETOT
RNATGSP1	.	.	.	.	.07950-	.	.	RNATGSP1
RNATGSP2	.	.	.	.	.	.07950-	.	RNATGSP2
RNATGSP3	.	.	.	.	.	.	.07950-	RNATGSP3
RNATGFR2	.66670	.	.	.	.	.	.	RNATGFR2
RNATGFR4	.41670	.	.	.	.	.	.	RNATGFR4
RNATGFR5	.33330	.	.	.	.	.	.	RNATGFR5
RNATGFR6	.33330	.	.	.	.	.	.	RNATGFR6
RMLABRP1	.12000	1.71000	1.71000	.	.	.	.	RMLABRP1
RMLABRP2	.12000	.36000	.72000	.	.	.	.	RMLABRP2
RMLABRP3	.53000	.	.50000	.	.	.	.	RMLABRP3
RMLABRP4	2.77000	.	.	.	.	.	.	RMLABRP4
RMLABRP5	.12000	.12000	.12000	.	.	.	.	RMLABRP5
RMLABRP6	.12000	1.85000	1.85000	.	.	.	.	RMLABRP6
RILABRP2	.98400	.	.	.	.	.	.	RILABRP2
RILABRP4	.61500	.	.	.	.	.	.	RILABRP4
RILABRP5	.49200	.	.	.	.	.	.	RILABRP5
RILABRP6	.49200	.	.	.	.	.	.	RILABRP6
RWHETSED	1.50000	.	.	.	.	.	.	RWHETSED
RWHTINST	.50000	.	.	.	.	.	.	RWHTINST
RNITROG4	140.00000	.	.	.	.	.	.	RNITROG4
RDIESEL1	.68000	.	.	.	.	.	.	RDIESEL1
RDIESEL2	.68000	.	.	.	.	.	.	RDIESEL2
RDIESEL3	1.36000	.	.	.	.	.	.	RDIESEL3
RDIESEL4	1.36000	.	.	.	.	.	.	RDIESEL4
RDIESEL5	.68000	.	.	.	.	.	.	RDIESEL5
RDIESEL6	.68000	.	.	.	.	.	.	RDIESEL6
RGASOLN1	.55000	.	.	.	.	.	.	RGASOLN1
RGASOLN2	.55000	.	.	.	.	.	.	RGASOLN2
RGASOLN3	1.10000	.	.	.	.	.	.	RGASOLN3
RGASOLN4	1.10000	.	.	.	.	.	.	RGASOLN4
RGASOLN5	.55000	.	.	.	.	.	.	RGASOLN5
RGASOLN6	.55000	.	.	.	.	.	.	RGASOLN6
RIFXCEQ2	1.00000	.	.	.	.	.	.	RIFXCEQ2
RFRFXCST	1.00000	.	.	.	.	.	.	RFRFXCST
RCASHFL1	.15000	3.75000	3.75000	.	1.50000	.	.	RCASHFL1
RCASHFL2	1.91000	10.50000	2.50000	.	.	1.50000	.	RCASHFL2
RCASHFL3	.59000	.	10.00000	.	.	.	1.50000	RCASHFL3
RCASHFL4	3.97000	2.00000	2.00000	.	.	.	.	RCASHFL4
RCASHFL5	1.03000	23.95000	23.95000	.64000	.	.	.	RCASHFL5
RCASHFL6	1.03000	3.75000	3.75000	.	.	.	.	RCASHFL6
RTPPAST1	.	1.89000	.	.	.	.	.	RTPPAST1

Table 30. (continued)

	WTGOFPP4	GRAZSTK1	GRAZSTK2	BUYSTOKR	NATGSPR1	NATGSPR2	NATGSPR3	
RTRPAST2	4.58000-	.	2.55000	.	.	.	.	RTRPAST2
RBUYSTOK	.	400.00000	400.00000	1.00000-	.	.	.	RBUYSTOK
RSELLTFD	.	613.00000-	.	.	.	.	.	RSELLTFD
RSELHVFD	.	.	744.00000-	.	.	.	.	RSELHVFD

Table 30. (continued)

	NATGSPR4	NATGSPR5	NATGSPR6	NATGFUR1	NATGFUR2	NATGFUR3	NATGFUR4	
OBJF	1.50000-	1.50000-	1.50000-	1.50000-	1.50000-	1.50000-	1.50000-	OBJF
RNATGSP4	.07950-	.	.	.	.	.	.	RNATGSP4
RNATGSP5	.	.07950-	.	.	.	.	.	RNATGSP5
RNATGSP6	.	.	.07950-	.	.	.	.	RNATGSP6
RNATGFR1	.	.	.	.13340-	.	.	.	RNATGFR1
RNATGFR2	.	.	.	.	.13340-	.	.	RNATGFR2
RNATGFR3	.	.	.	.	.	.13340-	.	RNATGFR3
RNATGFR4	.	.	.	.	.	.	.13340-	RNATGFR4
RCASHFL1	.	.	.	1.50000	.	.	.	RCASHFL1
RCASHFL2	.	.	.	.	1.50000	.	.	RCASHFL2
RCASHFL3	.	.	.	.	.	1.50000	.	RCASHFL3
RCASHFL4	1.50000	.	.	.	.	.	1.50000	RCASHFL4
RCASHFL5	.	1.50000	.	.	.	.	.	RCASHFL5
RCASHFL6	.	.	1.50000	.	.	.	.	RCASHFL6

Table 30. (continued)

	NATGFUR5	NATGFUR6	ELECSPR1	ELECSPR2	ELECSPR3	ELECSPR4	ELECSPR5	
OBJF	1.50000-	1.50000-	.03200-	.03200-	.03200-	.03200-	.03200-	OBJF
RNATGSP1	.	.	.00105-	.	.	.	.	RNATGSP1
RNATGSP2	.	.	.	.00105-	.	.	.	RNATGSP2
RNATGSP3	.	.	.	.	.00105-	.	.	RNATGSP3
RNATGSP4	.	.	.	.	.	.00105-	.	RNATGSP4
RNATGSP5	.	.	.	.	.	.	.00105-	RNATGSP5
RNATGFR5	.13340-	.	.	.	.	.	.	RNATGFR5
RNATGFR6	.	.13340-	.	.	.	.	.	RNATGFR6
RCASHFL1	.	.	.03200	.	.	.	.	RCASHFL1
RCASHFL2	.	.	.	.03200	.	.	.	RCASHFL2
RCASHFL3	.	.	.	.	.03200	.	.	RCASHFL3
RCASHFL4	.	.	.	.	.	.03200	.	RCASHFL4
RCASHFL5	1.50000	.	.	.	.	.	.03200	RCASHFL5
RCASHFL6	.	1.50000	.	.	.	.	.	RCASHFL6

Table 30. (continued)

	ELECSPR6	ELECFUR1	ELECFUR2	ELECFUR3	ELECFUR4	ELECFUR5	ELECFUR6	
OBJF	.03200-	.03200-	.03200-	.03200-	.03200-	.03200-	.03200-	OBJF
RNATGSP6	.00105-	.	.	.	.	.	.	RNATGSP6
RNATGFR1	.	.00175-	.	.	.	.	.	RNATGFR1
RNATGFR2	.	.	.00175-	.	.	.	.	RNATGFR2
RNATGFR3	.	.	.	.00175-	.	.	.	RNATGFR3
RNATGFR4	.	.	.	.	.00175-	.	.	RNATGFR4
RNATGFR5	.	.	.	.	.	.00175-	.	RNATGFR5
RNATGFR6	.	.	.	.	.	.	.00175-	RNATGFR6
RCASHFL1	.	.03200	.	.	.	.	.	RCASHFL1
RCASHFL2	.	.	.03200	.	.	.	.	RCASHFL2
RCASHFL3	.	.	.	.03200	.	.	.	RCASHFL3
RCASHFL4	.	.	.	.	.03200	.	.	RCASHFL4
RCASHFL5	.	.	.	.	.	.03200	.	RCASHFL5
RCASHFL6	.03200	.	.	.	.	.	.03200	RCASHFL6

Table 30. (continued)

```
              MLABORP1     MLABORP2     MLABORP3     MLABORP4     MLABORP5     MLABORP6     ILABORP1

OBJF          4.50000-     4.50000-     4.50000-     4.50000-     4.50000-     4.50000-     4.50000-     OBJF
RMLABRP1      1.00000-      .            .            .            .            .            .           RMLABRP1
RMLABRP2       .           1.00000-      .            .            .            .            .           RMLABRP2
RMLABRP3       .            .           1.00000-      .            .            .            .           RMLABRP3
RMLABRP4       .            .            .           1.00000-      .            .            .           RMLABRP4
RMLABRP5       .            .            .            .           1.00000-      .            .           RMLABRP5
RMLABRP6       .            .            .            .            .           1.00000-      .           RMLABRP6
RILABRP1       .            .            .            .            .            .           1.00000-     RILABRP1
RMAXLAB1      1.00000       .            .            .            .            .           1.00000      RMAXLAB1
RMAXLAB2       .           1.00000       .            .            .            .            .           RMAXLAB2
RMAXLAB3       .            .           1.00000       .            .            .            .           RMAXLAB3
RMAXLAB4       .            .            .           1.00000       .            .            .           RMAXLAB4
RMAXLAB5       .            .            .            .           1.00000       .            .           RMAXLAB5
RMAXLAB6       .            .            .            .            .           1.00000       .           RMAXLAB6
RCASHFL1      4.50000       .            .            .            .            .           4.50000      RCASHFL1
RCASHFL2       .           4.50000       .            .            .            .            .           RCASHFL2
RCASHFL3       .            .           4.50000       .            .            .            .           RCASHFL3
RCASHFL4       .            .            .           4.50000       .            .            .           RCASHFL4
RCASHFL5       .            .            .            .           4.50000       .            .           RCASHFL5
RCASHFL6       .            .            .            .            .           4.50000       .           RCASHFL6
```

Table 30. (continued)

```
          ILABORP2   ILABORP3   ILABORP4   ILABORP5   ILABORP6   HLABORP4   COTNINSR

OBJF      4.50000-   4.50000-   4.50000-   4.50000-   4.50000-   4.00000-    .12000-   OBJF
RILABRP2  1.00000-    .          .          .          .          .          .        RILABRP2
RILABRP3   .         1.00000-    .          .          .          .          .        RILABRP3
RILABRP4   .          .         1.00000-    .          .          .          .        RILABRP4
RILABRP5   .          .          .         1.00000-    .          .          .        RILABRP5
RILABRP6   .          .          .          .         1.00000-    .          .        RILABRP6
RMAXLAB2  1.00000     .          .          .          .          .          .        RMAXLAB2
RMAXLAB3   .         1.00000     .          .          .          .          .        RMAXLAB3
RMAXLAB4   .          .         1.00000     .          .          .          .        RMAXLAB4
RMAXLAB5   .          .          .         1.00000     .          .          .        RMAXLAB5
RMAXLAB6   .          .          .          .         1.00000     .          .        RMAXLAB6
RHLABRP4   .          .          .          .          .         1.00000-    .        RHLABRP4
RCOTNINS   .          .          .          .          .          .         1.00000-  RCOTNINS
RCASHFL2  4.50000     .          .          .          .          .          .        RCASHFL2
RCASHFL3   .         4.50000     .          .          .          .          .12000   RCASHFL3
RCASHFL4   .          .         4.50000     .          .         4.00000     .        RCASHFL4
RCASHFL5   .          .          .         4.50000     .          .          .        RCASHFL5
RCASHFL6   .          .          .          .         4.50000     .          .        RCASHFL6
```

Table 30. (continued)

	WHETINSR	CCRNSEED	COTNSEED	GRSOSEED	SOYBSEED	WHETSEED	CHRBCORN	
OBJF	.08000-	.90000-	.32000-	.45000-	.08000-	7.50000-	2.50000-	OBJF
RWHETINS	1.00000-	.	.	.	.	.	.	RWHETINS
RCORNSED	.	1.00000-	.	.	.	.	.	RCORNSED
RCOTNSED	.	.	1.00000-	.	.	.	.	RCOTNSED
RGRSOSED	.	.	.	1.00000-	.	.	.	RGRSOSED
RSOYBSED	.	.	.	.	1.00000-	.	.	RSOYBSED
RWHETSED	.	.	.	.	.	1.00000-	.	RWHETSED
RCORNHRB	.	.	.	.	.	.	1.00000-	RCORNHRB
RATRAZIN	.	.	.	.	.	.	3.00000	RATRAZIN
RCASHFL2	.	.90000	.32000	.45000	.	.	2.50000	RCASHFL2
RCASHFL3	.	.	.	.	.08000	.	.	RCASHFL3
RCASHFL4	.08000	.	.	.	.	7.50000	.	RCASHFL4

Table 30. (continued)

	CHRBCOTD	CHRBCOTI	CHRBGRSO	CHRBWHTI	HRBATRAZ	HRBTREFN	HRBPROPZ	
OBJF	2.50000-	2.50000-	2.50000-	2.50000-	3.50000-	3.50000-	3.00000-	OBJF
RCOTDHRB	1.00000-	.	.	.	.	.	.	RCOTDHRB
RCOTIHRB	.	1.00000-	.	.	.	.	.	RCOTIHRB
RGRSOHRB	.	.	1.00000-	.	.	.	.	RGRSOHRB
RWHETHRB	.	.	.	1.00000-	.	.	.	RWHETHRB
RATRAZIN	.	.	.	.	1.00000-	.	.	RATRAZIN
RTREFLAN	1.50000	1.50000	.	.	.	1.00000-	.	RTREFLAN
RPROPAZN	.	.	2.25000	.	.	.	1.00000-	RPROPAZN
R24DDDDD	.	.	.	2.00000	.	.	.	R24DDDDD
RCASHFL2	2.50000	2.50000	2.50000	.	3.50000	3.50000	3.00000	RCASHFL2
RCASHFL4	.	.	.	2.50000	.	.	.	RCASHFL4

Table 30. (continued)

	HRB24DDD	CINSCRN3	CINSCRN4	CINSCOTI	CINSGRSO	CINSWHTI	FURIDAN3	
OBJF	3.00000-	2.50000-	2.50000-	2.50000-	2.50000-	2.50000-	3.00000-	OBJF
R24DDDDD	1.00000-	.	.	.	.	.	.	R24DDDDD
RCRNINS3	.	1.00000-	.	.	.	.	.	RCRNINS3
RCRNINS4	.	.	1.00000-	.	.	.	.	RCRNINS4
RCOTINST	.	.	.	1.00000-	.	.	.	RCOTINST
RGRSINST	.	.	.	.	1.00000-	.	.	RGRSINST
RWHTINST	.	.	.	.	.	1.00000-	.	RWHTINST
RFURDAN3	.	1.00000	.	.	.	.	1.00000-	RFURDAN3
RFURDAN4	.	.	1.00000	.	.	.	.	RFURDAN4
RMALATHN	.	.	.	1.00000	.	.	.	RMALATHN
RMETPAR3	.	.	.	.	.50000	.	.	RMETPAR3
RMETPAR5	.	.	.	.	.	.50000	.	RMETPAR5
RCASHFL3	.	2.50000	.	2.50000	2.50000	.	3.00000	RCASHFL3
RCASHFL4	3.00000	.	2.50000	.	.	.	.	RCASHFL4
RCASHFL5	.	.	.	.	.	2.50000	.	RCASHFL5

Table 30. (continued)

	FURIDAN4	MALATHON	METHPAR3	METHPAR5	NITROGN2	NITROGN4	PHOSPHOR	
OBJF	3.00000-	3.50000-	3.00000-	3.00000-	.16000-	.16000-	.30000-	OBJF
RFURDAN4	1.00000-	.	.	.	.	.	.	RFURDAN4
RMALATHN	.	1.00000-	.	.	.	.	.	RMALATHN
RMETPAR3	.	.	1.00000-	.	.	.	.	RMETPAR3
RMETPAR5	.	.	.	1.00000-	.	.	.	RMETPAR5
RNITROG2	.	.	.	.	1.00000-	.	.	RNITROG2
RNITROG4	.	.	.	.	.	1.00000-	.	RNITROG4
RPHOSPHR	.	.	.	.	.	.	1.00000-	RPHOSPHR
RCASHFL2	.	.	.	.	.16000	.	.30000	RCASHFL2
RCASHFL3	.	3.50000	3.00000	.	.	.	.	RCASHFL3
RCASHFL4	3.00000	.	.	.	.	.16000	.	RCASHFL4
RCASHFL5	.	.	.	3.00000	.	.	.	RCASHFL5

Table 30. (continued)

	DIESELP1	DIESELP2	DIESELP3	DIESELP4	DIESELP5	DIESELP6	GASOLNP1	
OBJF	.50000-	.50000-	.50000-	.50000-	.50000-	.50000-	.50000-	OBJF
RDIESEL1	1.00000-	.	.	.	.	.	.	RDIESEL1
RDIESEL2	.	1.00000-	.	.	.	.	.	RDIESEL2
RDIESEL3	.	.	1.00000-	.	.	.	.	RDIESEL3
RDIESEL4	.	.	.	1.00000-	.	.	.	RDIESEL4
RDIESEL5	.	.	.	.	1.00000-	.	.	RDIESEL5
RDIESEL6	.	.	.	.	.	1.00000-	.	RDIESEL6
RGASOLN1	.	.	.	.	.	.	1.00000-	RGASOLN1
RCASHFL1	.50000	.	.	.	.	.	.50000	RCASHFL1
RCASHFL2	.	.50000	.	.	.	.	.	RCASHFL2
RCASHFL3	.	.	.50000	.	.	.	.	RCASHFL3
RCASHFL4	.	.	.	.50000	.	.	.	RCASHFL4
RCASHFL5	.	.	.	.	.50000	.	.	RCASHFL5
RCASHFL6	.	.	.	.	.	.50000	.	RCASHFL6

Table 30. (continued)

	GASOLNP2	GASOLNP3	GASOLNP4	GASOLNP5	GASOLNP6	CORNCOMB	GRSOCOMB	
OBJF	.50000-	.50000-	.50000-	.50000-	.50000-	.30000-	7.00000-	OBJF
RGASOLN2	1.00000-	.	.	.	.	.	.	RGASOLN2
RGASOLN3	.	1.00000-	.	.	.	.	.	RGASOLN3
RGASOLN4	.	.	1.00000-	.	.	.	.	RGASOLN4
RGASOLN5	.	.	.	1.00000-	.	.	.	RGASOLN5
RGASOLN6	.	.	.	.	1.00000-	.	.	RGASOLN6
RCCCORNN	.	.	.	.	.	1.00000-	.	RCCCORNN
RCCGRSOD	.	.	.	.	.	.	1.00000-	RCCGRSOD
RCASHFL2	.50000	.	.	.	.	.	.	RCASHFL2
RCASHFL3	.	.50000	.	.	.	.	.	RCASHFL3
RCASHFL4	.	.	.50000	.	.	.	.	RCASHFL4
RCASHFL5	.	.	.	.50000	.	.30000	7.00000	RCASHFL5
RCASHFL6	.	.	.	.	.50000	.	.	RCASHFL6

Table 30. (continued)

	GRSOCOMI	SOYBCOMB	WHTCOMBD	WHTCOMBI	COTNSAHL	COTAGING	CORNHAUL	
OBJF	.30000-	10.00000-	7.00000-	8.70000-	1.00000-	1.25000-	.05000-	OBJF
RCCGRSOI	1.00000-	.	.	.	.	.	.	RCCGRSOI
RCCSOYBN	.	1.00000-	.	.	.	.	.	RCCSOYBN
RCCWHETD	.	.	1.00000-	.	.	.	.	RCCWHETD
RCCWHETI	.	.	.	1.00000-	.	.	.	RCCWHETI
RCSHCOTN	.	.	.	.	1.00000-	.	.	RCSHCOTN
RGINCOTN	.	.	.	.	.	1.00000-	.	RGINCOTN
RHAULCRN	.	.	.	.	.	.	1.00000-	RHAULCRN
RCASHFL3	.	.	7.00000	8.70000	.	.	.	RCASHFL3
RCASHFLS	.30000	10.00000	.	.	1.00000	1.25000	.05000	RCASHFLS

Table 30. (continued)

	GRSOHAUL	SOYBHAUL	WHETHAUL	CORNDRYG	DRFXCEQP	FXCSTEQ1	FXCSTEQ2	
OBJF	.10000-	.10000-	.10000-	.10000-	7.35000-	10.50000-	13.65000-	OBJF
RHAULGRS	1.00000-	.	.	.	.	.	.	RHAULGRS
RHAULSOY	.	1.00000-	.	.	.	.	.	RHAULSOY
RHAULWHT	.	.	1.00000-	.	.	.	.	RHAULWHT
RDRYCORN	.	.	.	1.00000-	.	.	.	RDRYCORN
RDFXCEQP	.	.	.	.	1.00000-	.	.	RDFXCEQP
RIFXCEQ1	.	.	.	.	.	1.00000-	.	RIFXCEQ1
RIFXCEQ2	.	.	.	.	.	.	1.00000-	RIFXCEQ2
RCASHFL3	.	.	.10000	.	.	.	.	RCASHFL3
RCASHFL5	.10000	.10000	.	.10000	.	.	.	RCASHFL5

Table 30. (continued)

	SPFXCOST	FRFXCOST	BORROWP1	BORROWP2	BORROWP3	BORROWP4	BORROWP5	
OBJF	31.97000-	11.09000-	.01670-	.01670-	.01670-	.01670-	.01670-	OBJF
RSPFXCST	1.00000-	.	.	.	.	.	.	RSPFXCST
RFRFXCST	.	1.00000-	.	.	.	.	.	RFRFXCST
RCASHFL1	.	.	1.00000-	.	.	.	.	RCASHFL1
RCASHFL2	.	.	1.01670	1.00000-	.	.	.	RCASHFL2
RCASHFL3	.	.	.	1.01670	1.00000-	.	.	RCASHFL3
RCASHFL4	.	.	.	.	1.01670	1.00000-	.	RCASHFL4
RCASHFL5	.	.	.	.	.	1.01670	1.00000-	RCASHFL5
RCASHFL6	.	.	.	.	.	.	1.01670	RCASHFL6

Table 30. (continued)

	BORROWP6	INVSTRP1	INVSTRP2	INVSTRP3	INVSTRP4	INVSTRP5	INVSTRP6	
OBJF	.01670-	.00830	.00830	.00830	.00830	.00830	.00830	OBJF
RCASHFL1	.	1.00000	.	.	.	.	.	RCASHFL1
RCASHFL2	.	1.00830-	1.00000	.	.	.	.	RCASHFL2
RCASHFL3	.	.	1.00830-	1.00000	.	.	.	RCASHFL3
RCASHFL4	.	.	.	1.00830-	1.00000	.	.	RCASHFL4
RCASHFL5	.	.	.	.	1.00830-	1.00000	.	RCASHFL5
RCASHFL6	1.00000-	.	.	.	.	1.00830-	1.00000	RCASHFL6
RCASHFL7	1.01670	.	.	.	.	.	1.00830-	RCASHFL7

Table 30. (continued)

	SELLCORN	SELLCOTN	SELLCTSD	SELLGRSD	SELLSOYB	SELLWHET	SELLPAS1	
OBJF	2.10000	.48000	80.00000	4.25000	5.00000	3.40000	12.50000	OBJF
RCASHFL1	.	.	.	.	.	.	4.17000	RCASHFL1
RCASHFL2	.	.	.	.	.	.	4.17000	RCASHFL2
RCASHFL4	.	.	.	.	.	3.40000-	.	RCASHFL4
RCASHFL6	2.10000-	.48000-	80.00000-	4.25000-	5.00000-	.	4.17000	RCASHFL6
RSELLCRN	1.00000	.	.	.	.	.	.	RSELLCRN
RSELLCOT	.	1.00000	.	.	.	.	.	RSELLCOT
RSELLCTS	.	.	1.00000	.	.	.	.	RSELLCTS
RSELLGRS	.	.	.	1.00000	.	.	.	RSELLGRS
RSELLSOY	.	.	.	.	1.00000	.	.	RSELLSOY
RSELLWHT	.	.	.	.	.	1.00000	.	RSELLWHT
RTRPAST1	.	.	.	.	.	.	1.00000	RTRPAST1

Table 30. (continued)

	SELLPAS2	SELLLTFD	SELLHVFD	RS1	
OBJF	12.50000	.56000	.52000	.	OBJF
RCWATP01	.	.	.	538.42800	RCWATP01
RCWATP02	.	.	.	269.21400	RCWATP02
RCWATP03	.	.	.	269.21400	RCWATP03
RCWATP04	.	.	.	269.21400	RCWATP04
RCWATP05	.	.	.	269.21400	RCWATP05
RCWATP06	.	.	.	269.21400	RCWATP06
RCWATP07	.	.	.	269.21400	RCWATP07
RCWATP08	.	.	.	269.21400	RCWATP08
RCWATP09	.	.	.	269.21400	RCWATP09
RCWATP10	.	.	.	538.42800	RCWATP10
RACRETOT	.	.	.	640.00000	RACRETOT
RMAXLAB1	.	.	.	487.00000	RMAXLAB1
RMAXLAB2	.	.	.	854.00000	RMAXLAB2
RMAXLAB3	.	.	.	930.00000	RMAXLAB3
RMAXLAB4	.	.	.	955.00000	RMAXLAB4
RMAXLAB5	.	.	.	764.00000	RMAXLAB5
RMAXLAB6	.	.	.	584.00000	RMAXLAB6
RCASHFL1	4.17000	.	.	.	RCASHFL1
RCASHFL2	4.17000	.56000-	.	.	RCASHFL2
RCASHFL3	.	.	.52000-	.	RCASHFL3
RCASHFL6	4.17000	.	.	.	RCASHFL6
RTRPAST2	1.00000	.	.	.	RTRPAST2
RSELLTFD	.	1.03000	.	.	RSELLTFD
RSELHVFD	.	.	1.03000	.	RSELHVFD

APPENDIX C

STATISTICAL FUNCTIONS TO ESTIMATE CROP YIELDS: TEXAS HIGH PLAINS

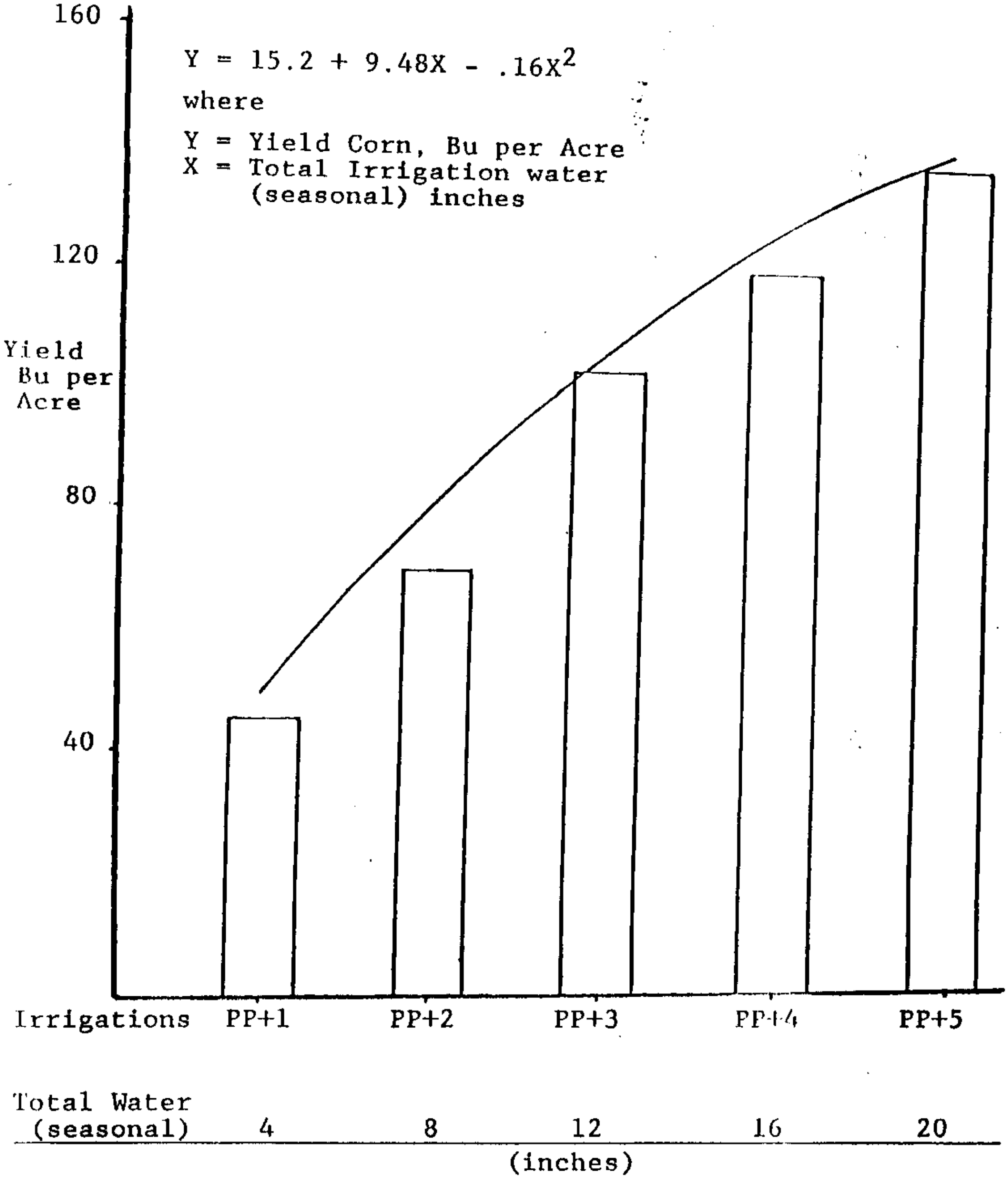

Figure 18. Production function for irrigated corn, furrow irrigation: Texas High Plains.

Source: Shipley 1978.

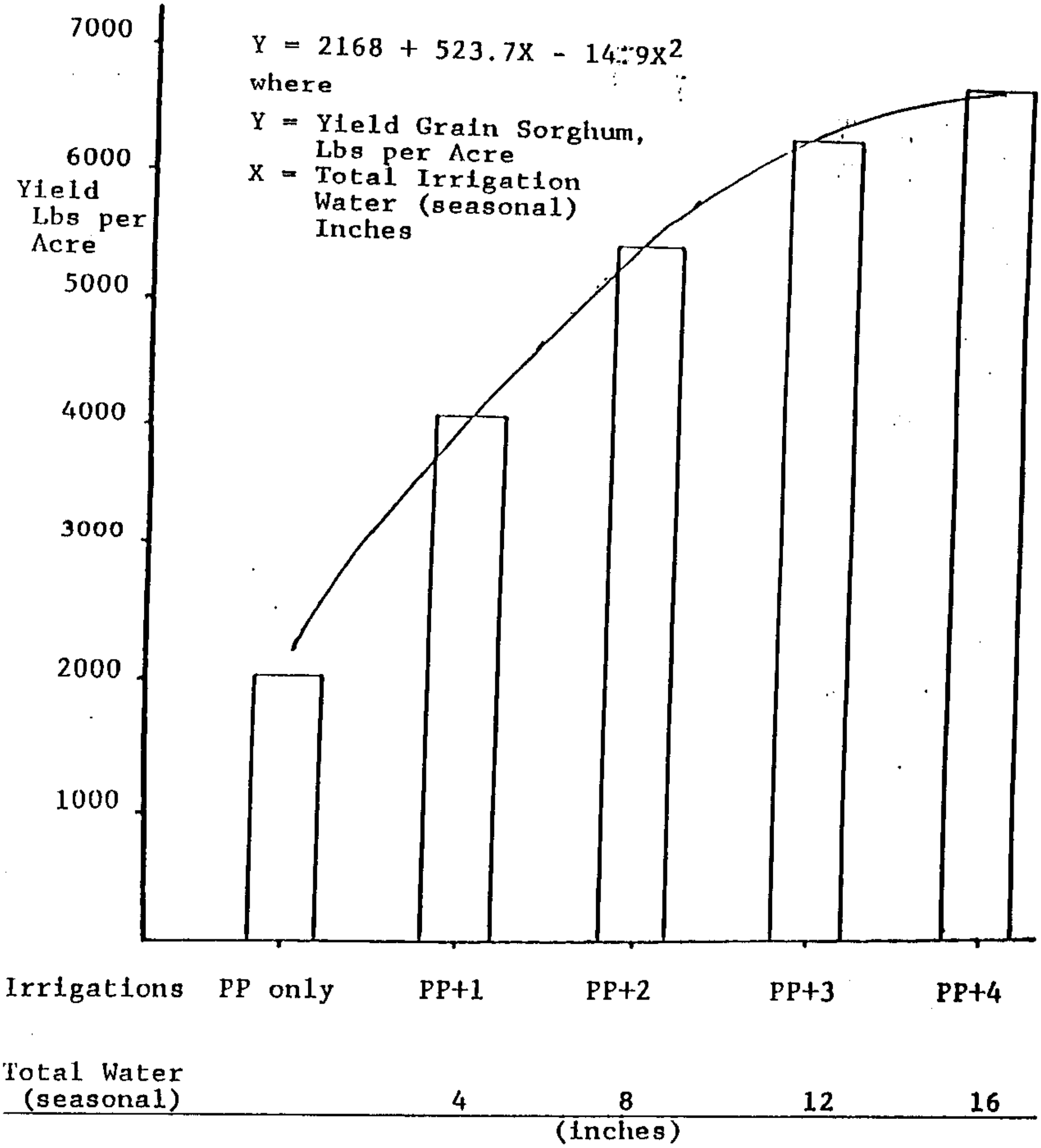

Figure 19. Production function for irrigated grain sorghum, furrow irrigation: Texas High Plains.

Source: Shipley 1977b.

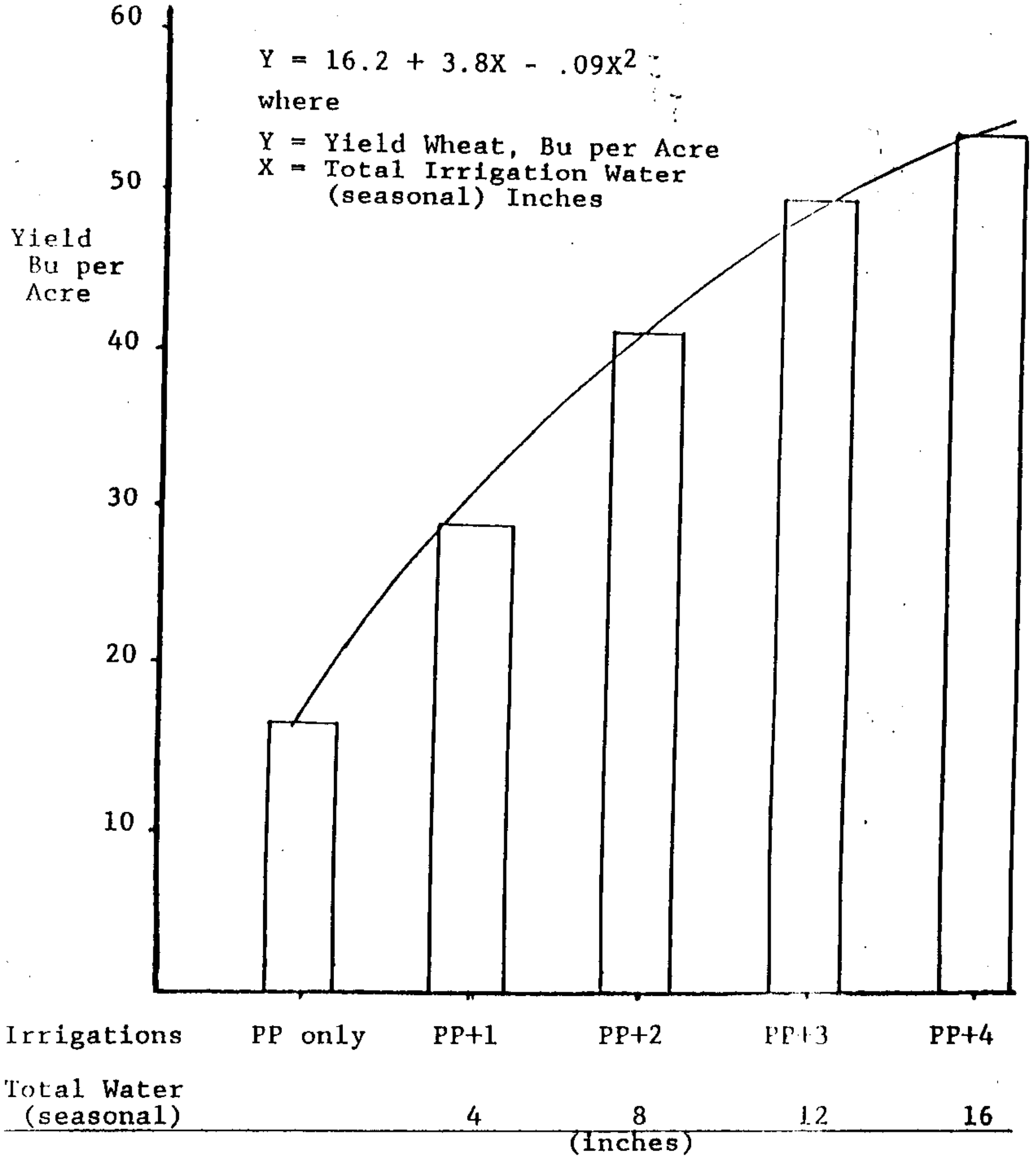

Figure 20. Production function for irrigated wheat, furrow irrigation: Texas High Plains.

Source: Shipley 1977b.

APPENDIX D

SHORT-RUN EFFECTS UPON CROPPING PATTERNS OF INCREASED NATURAL GAS PRICES, FOR OWNER-OPERATOR AND RENTER-OPERATOR: TEXAS HIGH PLAINS

Table 31. Effect of Increased Natural Gas Prices on Cropping Patterns for 640 Acres, a Typical Farm in Poor Water:[a] Texas High Plains.

Item	Natural Gas Price ($/mcf)									
	1.50		2.30		3.75		7.00		10.00	
	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter
Sprinkler										
Sorghum										
Dryland										
PP+2[b]	107	107	107	107	107	107	107	640	107	640
PP+3				533	533	533	533		533	
PP+4	533	533	533							
Furrow										
Cotton										
PP+2							458		458	389
PP+3	428	458	417		455					
Sorghum				458		458		458		
Dryland		11		14		14	14	14	14	251
PP+3			9		3					
Wheat										
Dryland	81	167	112	168	172	168	168	168	168	
PP+3	110	4	103		10					

---

[a] Poor water has a saturated thickness of 75 feet and a lift of 75 feet.

[b] PP+2 indicates one pre-plant plus two post-plant waterings, etc.

Table 32. Effect of Increased Natural Gas Prices on Cropping Patterns for 640 Acres, a Typical Farm in Good Water:[a] Texas High Plains.

Item	Natural Gas Price ($/mcf)											
	1.50		2.30		4.09		4.33		6.42		7.08	
	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter
Sprinkler												
Sorghum												
Dryland	107	107	107	107	107	107	107	640	107	640	640	640
PP+2[b]						533			533			
PP+3		533	533	533	533		533					
PP+4	533											
	1.50		2.42		4.33		4.56		4.99		6.57	
	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter
Furrow												
Cotton												
PP+1						389					389	
PP+2		458	458	458	458		458		389			
PP+3	455											
Sorghum												
Dryland		14	14	14	14	251	14	640	128	640	251	640
PP+3	3											
Wheat												
Dryland	172	168	168	168	168		168		94			

[a] Good water has a saturated thickness of 250 feet and a lift of 250 feet.

[b] PP+2 indicates one pre-plant plus two post-plant waterings, etc.