Reducing Irrigation Water Demand with Cotton Production in West Texas

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Abstract: Due to declining water availability from the Ogallala Aquifer and increasing pumping costs, irrigation management options for cotton are analyzed. The study concludes that supplemental irrigation while meeting crop ET requirements is the most profitable option. Switching from corn to cotton production may reduce irrigation water demand in the region.

Key Words: Ogallala Aquifer, irrigated cotton, irrigation efficiency, water response function, input use optimization, ET, Texas Panhandle.

Introduction: Agricultural production has been a major economic activity in the Texas Panhandle. The Ogallala Aquifer still remains the major source of groundwater used for irrigated agriculture. However, groundwater is a non-renewable natural resource and has begun to become scarce. The lack of water availability in some areas has led to corresponding declines in yields of crops that require large quantities of water. Declines in crop yields have a direct relationship on the profitability of the crop.

Natural gas is the most common energy source used to pump the water in the Texas Panhandle, and the price of natural gas has increased over the past few years. This increase in energy cost has led to an increase in the costs of irrigation. Despite increased input costs, commodity prices have not shown such an increase, which has resulted in the decline in profitability of the crops. This increase in irrigation cost accompanied with the ever decreasing supply of water has led to less farm profit for Texas Panhandle producers.

Due to the decrease in profits of agricultural crop production in the Texas Panhandle, area producers have begun to look for alternatives that can help to make the production system more profitable. Some of these alternatives include the use of more dry land (non-irrigated) farming, conservation tillage, precision irrigation systems, and even different crop selection. Several producers have determined it is better to turn off their wells as opposed to paying the high gas prices. Other farmers lack an adequate water supply to irrigate crops properly, and have been forced to shut down their wells and produce drought resistant dry land crops.

Perhaps the alternative of switching to a different crop and different farming system offers the highest returns, but it has the most risks associated with it and requires significant changes. In the Texas Panhandle, this different crop farming system has been cotton. Since the turn of the 21st century, cotton production has exploded northward into the Texas Panhandle.

Total cotton harvested acres in Carson county has increased from 1,000 acres in 2000 to 22,700 acres in 2004 (USDA, 2006).

Cotton not only requires a long growing season and large amount of heat, but cotton requires far less water than other top-producing crops such as corn. Decreased water requirements reduce the dependence on irrigation water quantity and expense. Agricultural producers in the Texas Panhandle are faced with a lack of available water for irrigation. Cotton is a crop which requires less water than other major crops such as corn and alfalfa. Several corn producers were forced to switch to other crops because their wells were not pumping enough water to produce a successful corn crop. Grain sorghum and soybeans are two other crops which have replaced corn production, but neither is as popular as cotton. Cotton is becoming increasingly more popular to area farmers because of the high profitability of the crop. High yields, lowered irrigation costs, and large government subsidies have led to high profit levels for cotton over the past few seasons.

A study conducted in 2000 and 2004 by the Panhandle Groundwater Conservation District used information from over 180 meters installed in the counties of Potter, Carson, Armstrong, Roberts, Gray, Wheeler, and Donley. The purpose of the study was to determine the amount of water required by different crops, peak times for irrigation, the distribution of crops throughout the districts, and the effects of irrigation patterns on the aquifer (Crowell, 2006). The results of the study indicated the average amount of water applied to crops. The results showed that the most water was applied to alfalfa and corn followed by wheat, soybeans, and grain sorghum. The least amount of water was applied to cotton. A little less than an average of 2.25 acre-feet was applied to alfalfa. An average of nearly 1.5 acre-feet was applied to corn, and an average amount of nearly 0.75 acre-feet was applied to cotton.

The increased expected return from cotton is a major reason for the expansion of cotton production into the Texas Panhandle. The reduced water use leads to reduced irrigation costs and increased economic return. With the possible increased economic return, cotton acres have increased in the 26 Panhandle counties from total harvested acres of 450,300 in 2000 to 488,100 in 2004. Production in these counties has increased from total bales of 467,500 in 2000 to 739,700 in 2004 (USDA NASS, 2006). This represents an 8.4% increase in total harvested acres.

Since there is no renewable surface source of irrigation water in the Texas Panhandle and only limited recharge of the Ogallala aquifer in this area, irrigation water is a fixed supply and excessive pumping results in shortening the economic life of the aquifer and reduces the returns to the resources held by the farmer (Amosson et al. 2001). Strategies that will maintain returns while conserving water are critical to the future of agriculture in the area.

Research Objectives: The general objective of this research is to analyze the profitability of irrigated cotton in the Texas Panhandle using alternative irrigation management approaches and estimate the potential water saving that can be realized with shift from high water use crops to cotton production. The specific objectives are to 1) estimate water use efficiency and water response function for irrigated cotton, 2) use the input response function to determine the optimum levels input to maximize output and return to management, and 3) estimate water saving potential due to shift from high water use crop production to irrigated cotton production in the area to reduce irrigation water demand.

Materials and Methods: This research focuses on analyzing the economic decisions affecting producers of irrigated cotton in the Texas Panhandle. This study analyzes the input variables affecting the cotton yield as well as optimal production decisions concerning management variables. These variables include total available water, total irrigation, total rainfall, and percent of potential evapotranspiration. In order to estimate a cotton lint yield response function to water which represents the Texas Panhandle, data were obtained from the Texas Cooperative Extension. Data included in this study represents production information collected from commercial producers cooperating in the AgriPartners program. Cooperating producers recorded irrigation, rainfall, soil water, and other production information weekly. Final crop production data was provided following harvest. Total water availability was measured and tabulated in comparison to corresponding seasonal water use reported by the North Plains PET Network for fully irrigated crops (New 1998-2005).

The water response function for cotton must be estimated before the marginal physical product and optimal water application rate can be determined. The response function shows the relationship between the yield and the amount of water used by the crop. One of the management tools available to producers is a measurement of water requirements for a given crop as indicated by potential evapotranspiration. ET is a measurement of the needs of the plant and is determined by biological and climatic factors. Since the producer has no control over the level of ET it may be used as a guide but cannot be considered a management factor. The ET requirement is based on Reference Evapotranspiration (ET_0) adjusted to reflect the demands of the specific crop. The reference evapotranspiration is adjusted by multiplying by the specific crop coefficient (K_C) which reflects biological factors such as the crop, maturity rating, and the stage of growth; and climatic conditions such as maximum and minimum temperatures, growing degree days (GDD-

56^{o}F), humidity, solar radiation, wind speed and direction, etc. Three sources of water to meet the ET requirement include residual soil moisture, natural precipitation, and irrigation. A producer has control over only one of these, irrigation. ET can be an aid to management decision making by indicating the amount of water that is needed by the plant. Applying water so that the ET requirement is just satisfied minimizes excessive application and subsequent water loss.

Information collected from the demonstrations include the number of acres, yield of the crop, variety, irrigation method, number of irrigations, amount of irrigation applied, total amount of rainfall for each month during the growing season, total amount of available water, cumulative potential evapotranspiration (PET), percent of PET, seeding rate, planting and harvesting date, soil type, amount and type of fertilizer, and any chemical applications. The demonstrations used for this study include all of the cotton demonstrations conducted since 1998. This encompasses a total of 86 demonstrations from 43 different producers in 14 different counties in the Texas Panhandle. The average amount of irrigation applied for all 86 observations is 11.52 acre inches. The average yield for all 86 observations is 1,039.27 pounds per acre (New, 98-05).

Three approaches to the estimation of the cotton-water response function are evaluated. In the first cotton production is defined as a function of total water available for the crop. In the second approach cotton production is viewed as a function of supplemental irrigation to correct for the deficiency in natural precipitation. And, in the third approach, the application of water to the crop is based on the ET requirements of the crop. The input cost for water is calculated by one uniform method for all three approaches.

Total cost is the sum of the fixed costs, the variable costs pertaining to the level of irrigation, and other variable input costs (Equation 1). These other variable input costs, excluding irrigation, are considered constant and are included in the fixed cost portion. These variable costs were determined from a 2006 projected costs and returns per acre budget for sprinkler irrigated cotton. After subtracting irrigation energy costs, irrigation labor, and maintenance costs from the budget, total direct expenses equaled $376.09 per acre (Amosson et al, 2005). Cottonseed revenue was determined to cover the total fixed expenses in the budget. An estimated government subsidy level, which an average farmer may receive through direct cyclical payments, was also determined. This level of government support was determined to be $21.21 per acre (Williams, 2006). After subtracting the government subsidy level from the total direct expenses, the fixed cost level used in this study equals $354.88 per acre.

$$TC = FC + (FULC + LMR + LC + AIC)\,AW \tag{1}$$

where: TC= total production cost, FC= fixed cost associated with the inputs at constant levels, FULC= fuel cost per acre inch of water, LMR= cost of lubrication, maintenance, and repairs, LC= labor cost per acre inch of water, AIC= annual investment cost per acre inch of water, and AW= amount of water available.

The cost of lubrication, maintenance, repairs, labor cost, annual investment cost per acre inch are constant coefficients determined from previous studies (Almas et al, 2004). These constant coefficients are determined to be $2.50 for LMR, $0.91 for LC, and $3.81 for AIC. With these coefficients held constant at a sum of $7.22, the total cost function is mostly affected by the various changes in fuel cost per acre inch of water pumped. In the Texas Panhandle, most irrigation delivery systems are fueled with natural gas; thus, the price of natural gas is used to determine the fuel cost (Equation 2).

$$FULC = NG^{*}\,P_{NG} \tag{2}$$

Where: Ng= quantity of natural gas, and P_{NG}= price of natural gas

The amount of natural gas needed to pump one acre inch of water varies between irrigation systems. The depth of the well or amount of lift required to bring water to the surface, in addition to the pressure and efficiency of the system are the factors affecting the cost of pumping. An equation is used from previous studies to determine the amount of gas used to pump one acre inch of water (Almas et al, 2004). For a Low Elevation Spray Application (LESA) system with a 350' lift the total cost equation would equate to (Equation 3).

$$TC = FC + (1.018P_{NG} + 2.50 + 0.91 + 3.81)\ AW$$

$$TC = FC + (1.018P_{NG} + 7.22)\ AW \qquad (3)$$

Once this total cost function is determined the MFC_{AW} is then determined by calculating the first derivative of the total cost function with respect to available water (Equation 4).

$$MFC_{AW} = \Delta TC/\Delta AW = 1.018P_{NG} + 7.22 \qquad (4)$$

Results and Discussion: Three approaches to the estimation of the cotton lint-water response function are evaluated. The first approach is the traditional approach in which cotton production is defined as a function of the total water available during the growing season. The quadratic form produces the best explanation of the relationship between cotton lint yield and water available with a $Pr>F_{(2,\,85)}=0.0001$ for the model and an R^2 of 0.35. The estimated coefficients for the terms representing water application are shown in Equation 5. The $Pr>t_{(85)}$ is in parentheses below the coefficients.

$$\begin{array}{l} Y = -377.0925 + 87.1218AW - 1.0879AW^2 \\ \qquad (0.1751) \qquad (0.0001) \qquad (0.0039) \end{array} \qquad (5)$$

The Marginal Physical Product of Water (MPP_{AW}) is equal to the derivative of the response function with respect to the input water (Equation 6). The Marginal Value Product of water (MVP_{AW}) is obtained by multiplying the Marginal Physical Product of water (MPP_{AW}) by the price of the product (P_Y) as given in Equation 7. The profit maximizing level of available water is determined by setting the MVP_{AW} equal to the MFC_{AW} and solving for the available water variable in Equation 8. Details are available in Warminski (2006)

$$MPP_{AW} = 87.1218 - 2.1758AW \tag{6}$$

$$MVP_{AW} = (87.1218 - 2.1758AW) * (P_Y) \tag{7}$$

$$(87.1218 - 2.1758AW) * (P_Y) = 1.018P_{NG} + 7.22 \tag{8}$$

The optimal economic level of a productive input is based on the principle of profit maximization (Heady and Dillon 1961; and Beattie and Taylor 1985). Profit is maximized at that input level where the increase in value from using an additional unit of input, Marginal Value Product, is equal to the increase in cost associated with the use of that same unit of input, Marginal Factor Cost. Table 1 illustrates the level of available water at various prices of cotton and natural gas in order to maximize profit. The optimization table shows the level of available water in order to maximize profit at a certain cotton and natural gas price. For example, when the cotton price is \$0.50/lb. and the natural gas price is \$7.00/mcf, the level of available water in order to maximize profit is 26.85 acre inches. This level of available water will not produce the highest possible cotton yield, but taking into account crop revenue and cost of irrigation, this level will result in the highest profit to the producer.

The amount of profit received at each optimal level of available water is displayed in Table 2. This profit table points out some key levels where it is not rational to irrigate cotton because the maximum possible profit is negative. Even when the optimal level of available water is achieved, the actual profit returned is still negative. However, it is still the optimal level of available water because it shows the level which minimizes loss. For example, as mentioned above, when the cotton price is \$0.50/lb. and the natural gas price is \$7.00/mcf, the profit maximizing level of available water is 26.85 acre inches. If this optimal level is reached when the cotton price is \$0.50/lb. and the natural gas price is \$7.00/mcf, the actual amount of profit received is \$32.62. However, if the cotton price drops to \$0.45/lb and the natural gas price remains at \$7.00/mcf, the actual amount of profit received drops to \$-25.23. At this level it is infeasible to irrigate because profits are negative. When the natural gas price is \$7.00/mcf, it is infeasible to irrigate cotton until the price of cotton is nearly \$0.50/lb. Similarly, when the price of cotton is \$0.50/lb it is only rational to irrigate when the natural gas price is \$9.00/mcf or lower.

The second approach is to define the production function of cotton as a function of the irrigation water added to the natural precipitation available during the growing season. The best response function relating the production of cotton to the water available through natural precipitation and supplemental irrigation is linear in natural precipitation and quadratic with respect to the supplemental water added through irrigation. The model has a $Pr>F_{(3,85)}=0.0001$ with an R^2 of 0.32. The estimated coefficients for the terms representing water application are shown in Equation 9. The $Pr>t_{(85)}$ is in parentheses below the coefficients.

$$\begin{array}{l} Y= \underset{(0.0054)}{362.9303} + \underset{(0.0284)}{59.0401}IW - \underset{(0.0001)}{0.9884}IW^2 + \underset{(0.0105)}{20.8839}RW \end{array} \tag{9}$$

Where: Y= cotton yield, IW= applied irrigation water inches per acre, and RW= rainfall amount in inches. The level of irrigation water needed to maximize profit is determined for various prices of cotton and natural gas. The profit maximizing level of irrigation water is determined by setting the MVP_{IW} equal to the MFC_{IW} and solving for the irrigation water variable. Table 3 illustrates the level of irrigation at various prices of cotton and natural gas in order to maximize profit. The optimization table shows the level of irrigation water in order to maximize profit at a certain cotton and natural gas price. For example, when the cotton price is $0.50/lb. and the natural gas price is $7.00/mcf, the level of irrigation water in order to maximize profit is 15.35 acre inches. This level of irrigation water will not produce the highest possible cotton yield, but taking into account crop revenue and cost of irrigation, this level will result in the highest profit to the producer. Since the applied irrigation model contains a rainfall variable, the tables are broken into three levels of rainfall. Table 4 displays the amount of profit received at each optimal level of irrigation water for various prices of cotton and natural gas with a low rainfall amount of 9.86 inches during the growing season. Table 5 and 6 display the level of profit for average and high seasonal rainfall of 12.81 and 15.76 inches, respectively.

Table 4 profit table points out some key levels where it is not rational to irrigate cotton because the maximum possible profit is negative. In some cases when the optimal level of irrigation water is achieved, the actual profit returned is still negative. However, it is still the optimal level of irrigation water because it shows the level which minimizes loss. For example, as mentioned above, when the cotton price is $0.50/lb. and the natural gas price is $7.00/mcf, the profit maximizing level of irrigation water is 15.35 acre inches. If this optimal level is applied when the cotton price is $0.50/lb. and the natural gas price is $7.00/mcf, the actual profit level is $46.01 (Table 4). However, when the cotton price drops to $0.45/lb. and the natural gas prices remains at $7.00/mcf, the actual level of profit drops to $-14.94. This level of profit shows it is infeasible to irrigate cotton when the price of natural gas is $7.00/mcf and the cotton price is only $0.45/lb (shaded area in Table 4). When the natural gas price is $7.00/mcf, it is infeasible to irrigate cotton until the price of cotton is nearly \$0.50/lb. Similarly, when the price of cotton is \$0.45/lb it is only rational to irrigate when the natural gas price is \$5.50/mcf or lower. When the amount of seasonal rainfall is increased to an average of 12.81 inches, the actual profit realized when the cotton price is \$0.50/lb. and the natural gas price is \$7.00/mcf is \$76.82 per acre (Table 5). When the amount of seasonal rainfall is further increased to a high level of 15.76 inches, the actual profit received when the cotton price is \$0.50/lb. and the natural gas price is \$7.00/mcf is \$107.62 per acre (Table 6). Even with this high level of rainfall there are still combinations of natural gas and cotton prices where it is infeasible to irrigate. When the price of cotton is \$0.40/lb. it is not rational to irrigate once the price of natural gas is nearly \$5.50/mcf.

The third approach is to determine the application of an input based on the physiological requirement of the crop. In this case, basing the application of water on the physiological requirements of the crop as determined by Potential Evapotranspiration (ET). In the third model the production of cotton is defined as a function of the relationship between the amount of water available and the amount of water required for the growing plant as indicated by the Percent of Potential Evapotranspiration (PET).

The model determines the PPET variable to be quadratic in affecting cotton yield, and the available water variable to be linear in affecting the PPET. The quadratic form produces the best explanation of the relationship between cotton lint yield and water available to meet ET requirements with a $Pr>F_{(2,83)}=0.0001$ for the model. The R^2 is 0.31. The estimated coefficients for the terms representing water application are shown in Equation 10. The $Pr>t_{(83)}$ is in parentheses below the coefficients.

$$\begin{array}{l} Y= \underset{(0.6231)}{-107.2886} + \underset{(0.0001)}{20.7934PPET} - \underset{(0.0007)}{0.0721PPET^2} \end{array} \qquad (10)$$

Since PET is a measurement instead of an input, the productivity of the PET must reflect the relationship between PET and water availability and the best estimate is a linear model given in Equation 11 with a probability of a greater F-value of less than 0.0001. The model has a coefficient of determination of 0.84, which illustrates the variation in the PPET explained by water availability. The $Pr>t_{(84)}$ is in parentheses below the coefficients.

$$\underset{}{PPET} = \underset{(0.1009)}{-8.28067} + \underset{(0.0001)}{4.13181}AW \tag{11}$$

Since PET does not refer to units of water or price the chain rule is utilized to determine the Marginal Physical Product of water based on PET. The level of available water required to maximize profit and meet the requirements of the PET is determined by setting the MVP_{AW} equal to the MFC_{AW} and solving for the available water variable. Table 7 illustrates the level of available water required to maximize profit and meet the PET requirement at a certain cotton and natural gas price. For example, when the cotton price is \$0.50/lb. and the natural gas price is \$7.00/mcf, the level of available water in order to maximize profit and meet the PET requirement is 25.25 acre inches which is less than the corresponding optimal level in case of first approach.

Summary: Three approaches to making the management decision on the amount of water to apply to maximize profits and returns to resources from cotton production are evaluated. The traditional approach of determining the optimum level of water application based on the total availability without regard for the origin of the water provides a response function indicating the total water needs but only indirectly addressing the management decision of irrigation levels. It has been found that the level of available water in order to maximize profit is 26.85 acre inches at cotton price of \$0.50 per pound and natural gas price of \$7.00 per mcf.

In the second approach, irrigation is viewed as a supplementation to natural precipitation. Irrigation becomes a management decision variable. The response function indicates that cotton production increases as both natural precipitation and irrigation increase. The response is linear with respect to natural precipitation and quadratic with respect to irrigation. This may be due to the fact that natural precipitation is in the Panhandle is never sufficient to meet the total evapotranspiration needs of the crop. Therefore, we only observe response in the linear portion of the production function. On the other hand, irrigation moves the total water availability into the range where efficiency declines rapidly and the response per unit of input declines. This approach provides a measurement of the actual irrigation levels that would be relevant to the management decision. For example, when the cotton price is $0.50/lb. and the natural gas price is $7.00/mcf, the level of irrigation water in order to maximize profit is 15.35 acre inches.

The third approach is to base irrigation management decisions on the needs of the crop as indicated by potential evapotranspiration for a crop that is not limited by water availability. This method would be more valuable if a dynamic model which could account for the timing of irrigation application were available instead of a static model. It is interesting to note how low the optimal percent evapotranspiration levels are compared to the 100 percent PET level that would provide a water stress free environment for the crop. For example, when the cotton price is $0.50/lb. and the natural gas price is $7.00/mcf, the level of available water in order to meet the PET requirements and maximize profit is 25.25 acre inches.

For future studies researchers may want to analyze the PPET more closely. This can be done by determining the PET levels at certain growth stages throughout the year. However, it will necessary to document the growth stages of the cotton plants uniformly across each demonstration. Even though this study uses an estimation of the level of government subsidies in order to determine profit, it may be desirable to analyze the government subsidy level in greater depth and determine how profit reacts to changes in the subsidy level. Future cotton production may also be affected by changes in the subsidy level.

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Table 1: Optimum level of available water in acre-inches under alternative combinations of natural gas and cotton price

P_{ng} ($/mcf)	**Price of Cotton ($/lb.)**							
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**
6.50	21.87	24.14	25.91	27.32	28.48	29.44	30.26	30.96
7.00	21.20	23.56	25.39	26.85	28.05	29.05	29.90	30.62
7.50	20.53	22.97	24.87	26.39	27.63	28.66	29.54	30.29
8.00	19.87	22.39	24.35	25.92	27.20	28.27	29.18	29.95
8.50	19.20	21.80	23.83	25.45	26.78	27.88	28.82	29.62
9.00	18.53	21.22	23.31	24.98	26.35	27.49	28.46	29.29
9.50	17.86	20.63	22.79	24.52	25.93	27.10	28.10	28.95
10.00	17.19	20.05	22.27	24.05	25.50	26.71	27.74	28.62
10.50	16.52	19.46	21.75	23.58	25.08	26.32	27.38	28.28
11.00	15.86	18.88	21.23	23.11	24.65	25.93	27.02	27.95

Table 2: Level of profit at the optimum level of available water under alternative combinations of natural gas and cotton price

P_{ng} ($/mcf)	**Price of Cotton ($/lb.)**							
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**
6.50	-127.47	-74.83	-18.69	39.89	100.25	161.94	224.65	288.18
7.00	-131.91	-80.45	-25.23	32.62	92.38	153.57	215.87	279.03
7.50	-136.01	-85.77	-31.50	25.59	84.73	145.40	207.26	270.04
8.00	-139.78	-90.79	-37.50	18.80	77.30	137.43	198.84	261.23
8.50	-143.20	-95.52	-43.24	12.25	70.08	129.66	190.60	252.59
9.00	-146.28	-99.95	-48.72	5.93	63.08	122.09	182.54	244.12
9.50	-149.02	-104.08	-53.93	-0.14	56.29	114.72	174.67	235.82
10.00	-151.42	-107.91	-58.88	-5.98	49.72	107.54	166.98	227.69
10.50	-153.48	-111.45	-63.56	-11.58	43.37	100.56	159.47	219.73
11.00	-155.20	-114.68	-67.98	-16.95	37.24	93.78	152.15	211.94

Table 3: Optimum level of irrigation water in acre-inches under alternative combinations of natural gas and cotton price

P_{ng} ($/mcf)	**Price of Cotton ($/lb.)**							
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**
6.50	9.87	12.37	14.31	15.87	17.14	18.20	19.10	19.87
7.00	9.13	11.72	13.74	15.35	16.67	17.77	18.70	19.50
7.50	8.40	11.08	13.17	14.84	16.20	17.34	18.30	19.13
8.00	7.66	10.44	12.59	14.32	15.73	16.91	17.91	18.76
8.50	6.92	9.79	12.02	13.81	15.27	16.48	17.51	18.39
9.00	6.19	9.15	11.45	13.29	14.80	16.05	17.12	18.03
9.50	5.45	8.50	10.88	12.78	14.33	15.62	16.72	17.66
10.00	4.72	7.86	10.31	12.26	13.86	15.20	16.32	17.29
10.50	3.98	7.22	9.73	11.75	13.39	14.77	15.93	16.92
11.00	3.25	6.57	9.16	11.23	12.93	14.34	15.53	16.56

Table 4: Level of profit at the optimal level of irrigation water and low seasonal rainfall of 9.86 inches under alternative combinations of natural gas and cotton price

P_{ng} ($/mcf)	**Price of Cotton ($/lb.)**							
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**
6.50	-122.10	-66.88	-7.80	53.96	117.67	182.86	249.17	316.37
7.00	-126.94	-73.01	-14.94	46.01	109.07	173.71	239.55	306.36
7.50	-131.40	-78.81	-21.79	38.33	100.70	164.77	230.14	296.53
8.00	-135.49	-84.29	-28.35	30.91	92.58	156.05	220.92	286.88
8.50	-139.20	-89.43	-34.61	23.75	84.69	147.55	211.91	277.43
9.00	-142.53	-94.25	-40.59	16.85	77.04	139.27	203.09	268.16
9.50	-145.50	-98.75	-46.27	10.22	69.62	131.21	194.48	259.08
10.00	-148.09	-102.91	-51.66	3.85	62.45	123.37	186.07	250.18
10.50	-150.30	-106.75	-56.76	-2.26	55.51	115.74	177.86	241.47
11.00	-152.14	-110.26	-61.57	-8.11	48.81	108.34	169.86	232.95

Table 5: Level of profit at the optimal level of irrigation water and average seasonal rainfall of 12.81 inches under alternative combinations of natural gas and cotton price

P_{ng} ($/mcf)	**Price of Cotton ($/lb.)**							
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**
6.50	-100.54	-42.23	19.92	84.76	151.56	219.82	289.22	359.50
7.00	-105.38	-48.36	12.78	76.82	142.95	210.67	279.60	349.48
7.50	-109.84	-54.17	5.93	69.13	134.59	201.73	270.18	339.65
8.00	-113.92	-59.64	-0.62	61.71	126.46	193.02	260.97	330.01
8.50	-117.63	-64.79	-6.89	54.55	118.57	184.52	251.95	320.55
9.00	-120.97	-69.61	-12.86	47.66	110.92	176.24	243.14	311.28
9.50	-123.93	-74.10	-18.54	41.02	103.51	168.18	234.53	302.20
10.00	-126.52	-78.27	-23.94	34.65	96.33	160.33	226.12	293.31
10.50	-128.74	-82.10	-29.04	28.54	89.39	152.71	217.91	284.60
11.00	-130.58	-85.61	-33.84	22.69	82.70	145.30	209.90	276.08

Table 6: Level of profit at the optimal level of irrigation water and high seasonal rainfall of 15.76 inches under alternative combinations of natural gas and cotton price

P_{ng} ($/mcf)	**Price of Cotton ($/lb.)**							
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**
6.50	-78.98	-17.59	47.64	115.56	185.44	256.79	329.26	402.62
7.00	-83.81	-23.72	40.50	107.62	176.84	247.63	319.64	392.61
7.50	-88.27	-29.52	33.66	99.94	168.47	238.70	310.23	382.78
8.00	-92.36	-35.00	27.10	92.52	160.34	229.98	301.01	373.13
8.50	-96.07	-40.15	20.84	85.36	152.45	221.48	292.00	363.68
9.00	-99.41	-44.97	14.86	78.46	144.80	213.20	283.18	354.41
9.50	-102.37	-49.46	9.18	71.83	137.39	205.14	274.57	345.33
10.00	-104.96	-53.62	3.79	65.45	130.22	197.30	266.16	336.43
10.50	-107.17	-57.46	-1.31	59.34	123.28	189.67	257.95	327.72
11.00	-109.01	-60.97	-6.12	53.50	116.58	182.26	249.95	319.20

Table 7: Optimum level of available water required to maximize profit and meet the PET requirement for cotton production in the Texas Panhandle under alternative combinations of cotton and natural gas price.

P_{ng} ($/mcf)	**Price of Cotton ($/lb.)**							
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**
6.50	20.84	22.85	24.41	25.66	26.68	27.54	28.26	28.87
7.00	20.25	22.33	23.95	25.25	26.31	27.19	27.94	28.58
7.50	19.66	21.82	23.49	24.83	25.93	26.85	27.62	28.28
8.00	19.07	21.30	23.03	24.42	25.56	26.50	27.30	27.99
8.50	18.48	20.78	22.57	24.01	25.18	26.16	26.98	27.69
9.00	17.89	20.27	22.12	23.59	24.80	25.81	26.67	27.40
9.50	17.30	19.75	21.66	23.18	24.43	25.47	26.35	27.10
10.00	16.71	19.23	21.20	22.77	24.05	25.12	26.03	26.81
10.50	16.12	18.72	20.74	22.35	23.68	24.78	25.71	26.51
11.00	15.53	18.20	20.28	21.94	23.30	24.43	25.39	26.22