THE JOURNAL OF ECONOMIC SCIENCES: THEORY AND PRACTICE, V.70, # 1, 2013, pp. 4-22

THE WATER REQUIREMENT AND PROFITABILITY ANALYSIS OF CORN USING IRRIGATION MANAGEMENT APPROACHES INCLUDING EVAPOTRANSPIRATION AND WEATHER DATA

XiaolinQu, M.S.
Graduate Research Assistant
Department of Agricultural Sciences
West Texas A&M University
Canyon, TX 79016

Lal K. Almas, Ph.D.
Fulbright Scholar and Professor
Department of Agricultural Sciences
West Texas A&M University
Canyon, TX 79016
E-mail: lalmas@wtamu.edu

Received 14 January 2013; accepted 10 May 2013; published online 15 July 2013

Abstract

By using the corn demonstrations from a local research, the production functions for corn with respect to total available water (TW), irrigation application and Percentage of Potential Evapotranspiration (PPET) are established to represent the conditions in the Texas Panhandle area. The production functions and the total cost function generated are used to determine the optimal level of water application and the corresponding maximized profit. Also the benefits of ET information is analyzed and proved to be valuable in the decision-making process aimed at improving water-use efficiency.

Key words: corn, irrigation efficiency, yield-water response function, ET

JEL Classification Codes: Q15

Introduction

The Texas High Plain is a major producer of irrigated and dryland crops in the United States. Historically, agriculture activity is the major economic activity in this area. The High Plain accounted for over 40 percent of the value of agricultural production for the state of Texas. Not only leading the state in the production of feed grain, wheat, and cotton, this area also has fed about 13.3 million cattle and calves in the year of 2010 (2010 State Agriculture Overview, 2010).

Texas Panhandle area lies on the Northern Texas High Plain, consisting of the northernmost 26 counties in the state. Dryland farming has played an important role since the introduction of farming in the Panhandle area in the late 1800s. It was estimated that the application of irrigation has increased yield by two to seven times over dryland production in this area (Colette et al., 2007). With the significant yield improvement from applying irrigation, irrigation soon became the approach for the producers to increase crop profits. It was found that irrigation is very essential to maintain the regional economy (Colette et al., 2004).

During the 1950s, irrigation development in the Panhandle area started to accelerate. From 1950s to 1980s, irrigated areas increased. However beginning in 1974, irrigated area was started to decrease (Colette et al., 2008). The decline of the irrigated area was due to both the rise in energy costs and the less availability of the ground water, which is mainly from the Ogallala Aquifer.

The Ogallala Aquifer, also known as the High Plains Aquifer, is the major water-bearing formation of the Panhandle area. It supports the major irrigated agricultural production and processing base, municipal and industrial water needs.

In the Panhandle area, of the water obtained from the Ogallala Aquifer, approximately 90 percent is used for irrigation (Amosson et al., 2006).

The Ogallala Aquifer, however, is essentially a closed basin and withdrawals greatly exceed the recharge, which together with the overdraft for irrigation have led to a severe decline in its water table (Colaizzi et al., 2008). It was estimated that the total water in storage in 2009 was about 2.9 billion acre-feet, which was a decline of about 273 million acre-feet (or about 9 percent) since predevelopment. The area-weighted,average water-level change from predevelopment to 2009 was a decline of 14 feet and the water-level change in aquifer levels in different states ranges from an increase of 84 feet in Nebraska to a 234 feet decrease in Texas (McGuir, 2011) (table 1).

In order to conserve the water extracted from the Ogallala Aquifer for irrigation, irrigation technology has been improved in the Panhandle area. As a result, center pivot increased steadily from 1989 and more rapidly thereafter, reaching 72 percent by 2000 (Colaizzi et al., 2008).

Despite efficiency of the central pivot system, especially when designed with LEPA or LESA irrigation packages which are highly applied in the Texas Panhandle area, Studies show that irrigators generally tend to over irrigate when compared to actual crop requirements (Marek, 1996). This is especially true for irrigated corn, which is a major commodity within the area due to the intensive, major confined animal feeding industry. Thus, in order to efficiently utilize the declining groundwater supplies through efficient irrigation practice, it is claimed that there is a need for utilizing daily Evapotranspiration (ET) data for numerous crops grown within this intensive northern Texas agricultural region to provide accurate water use data to these agricultural producers.

ET is the combination of the concepts of both evaporation (E) and transpiration (T) to describe the total water escaping from a crop to the air (Rogers, 2007). Evaporation is referred to the process of water-molecule transferring from any moist surface to the air. Transpiration is the process of the water vapor escaping from plant leaves from the tiny pores scattered over the leaf surface. Since those two processes are closely intertwined and difficult to separate, ET is always referred to as “crop water use”.

Soil moisture, natural precipitation and irrigation application are three sources to meet ET requirement. Crop water use determines how much water is needed that may be provided by rain, or both rain and irrigation. The accurate application of crop water use is important because too little water can reduce crop yield while too much water, which is irrigation, can lead to waste of energy and water as well as accelerate the depletion of water resources.

When calculating ET for a specific crop, Potential Evapotranspiration (PET) is used. PET is the amount of water that a well-irrigated crop uses (Colette, 2004).

PET reflects biological factors such as the crop maturity rating and the stage of growth and climatic conditions. The climatic conditions include the maximum and minimum temperatures, growing degree days (GDD at 56 Degreees Fahrenheit), humidity, solar radiation, wind speed and direction (Colette et al., 2004). PET is obtained by entering the weather data into the corresponding equations. However, to be able to apply this for other crops, PET needs to be adjusted to obtain actual crop ET. Once PET is calculated, actual ET can be determined by multiplying PET with the crop coefficients (K_{co}). $K_{co}$is also known as adjustment factor, which is the ratio of observed crop water use to PET (Rogers, 2007).

The general objective of this study is to calculate the optimum levels of TW, irrigation application and PPET for growing corn in the Texas Panhandle area in order to obtain the maximum profits. The specific objectives are: 1) develop the production functions for corn with respect to TW, irrigation and PPET which are able to represent the conditions in the Texas Panhandle area; 2) use the production functions to determine the optimum levels of TW, irrigation application and the PPET in order to maximize profit. Then calculate the maximized profit at the optimum levels of the three water approaches respectively; 3) estimate potential benefits of ET Network in the irrigated agriculture in the study area.

Data and Methods

Data

The data used in this study are obtained from Texas Cooperative Extension's ten-year (1998-2007) program called Panhandle Agripartners Demonstration Program. 129 demonstrationsare extracted including the information of yield of corn, amount of irrigation applied, irrigation methods, total water availability, and PPET to analyze the yield-water relations.

Methods

In order to find out the relationship between water approaches including total available water (TW), irrigation application, as well as Percent of Potential Evapotranspiration (PPET) and the yields of corn, three models are developed. The first model describes the corn yield as a function of TW. The second model defines the corn yield as a function of the amount of irrigation applied. The third model uses the PPET requirement of each crop to predict corn yield. Regression analysis in Excel is used to evaluate the models under each approach and the models that fit best will be chosen to represent the production functions for the four crops in the Texas Panhandle area.

Based on the production functions under the three water approaches, the corresponding Marginal Physical Product (MPP) could be determined. Combining with the price of corn, which is a range of \$3/bushel - \$7.5/bushel, Marginal Value Product is determined. On the cost side, Marginal Factor Cost (MFC) is obtained from the Total Cost functions. Equating MFC to MVP will get the optimal levels of corn yield under a range of corn price and natural gas price.

Production cost

Production cost is comprised of fixed cost and variable cost. Fixed cost is not dependent on the level of input applied or the output produced. Since this study focuses on the yield-water response relations, the variable costs other than irrigation are assumed to be fixed. Since all irrigation in this region depends on groundwater, the variable cost associated with irrigation is limited to pumping and application cost. Therefore, the variable cost associated with the level of irrigation is made up of the fuel cost; cost of lubrication, maintenance, and repairs; labor costs; and annual investment costs (Equation 1) (Almas et al. 2000)

$$TC = FC + (FULC + LMR + LC + AIC)*W \qquad (1)$$

Where:

TC is the total production cost,

FC is the fixed cost associated with the inputs at constant levels,

FULC is the fuel cost per acre inch of water,

LMR is the cost of lubrication, maintenance and repairs,

LC is labor cost per acre inch of water,

AIC is annual investment cost per acre inch of water, and

W is the amount of water available to meet ET requirements.

In order to show the impact of a change in the price of fuel to the cost, a range of fuel price from \$2/mcf to \$7/mcf is applied in the calculation of cost. In the calculation of FULC, natural gas is used since it is the predominate source of energy for pumping irrigation water in the Texas Panhandle area. The fuel cost (FULC) is equal to the product of the amount of fuel used (NG) multiplied by the price of the fuel (PNG)(Equation 2) (Colette et al. 2004).

$$FULC = NG*P_{NG} \qquad (2)$$

Where NG is the amount of natural gas used in million cubic feet (mcf), P_{NG} is the price of natural gas (\$). The amount of natural gas needed (NG) to pump one acre-inch of water differs among irrigation systems (Equation 3) (Almas, 2000).

$$NG= 0.0038*L+ 0.0088*PSI – 0.000007623* PSI*L – 0.0000033*L^2 \qquad (3)$$

Where L is the system lift in feet and PSI is the system pressure per square inch

The NG, LMR, LC and AIC are known constants for a given irrigation system (Almas et al, 2000). For example, the total cost function for a typical Low Elevation Spray Application (LESA) system with a 350 foot system lift can be expressed as Equation 4. And Equation 4 is the cost function being used in this study to analyze the optimum problem across the three water approaches.

$$TC= FC+ (1.018*P_{NG} +4.04 + 0.56+1.06)*W= FC+ (1.018*P_{NG} + 5.66)*W \qquad (4)$$

Where W represents the water approaches including total available water, irrigation application and PPET. Marginal Factor Cost (MFC) represents the additional cost to the total cost when applying one more unit of input. MFC equals to the first derivative of TC (Equation 5).

$$MFC= 1.018*P_{NG} + 5.66 \qquad (5)$$

Results and Discussion

By analyzing the 129 demonstrations with regression analysis in Excel, the summary of the statistic results of corn yield and the three water approaches is shown in table 2. Quadratic regression model is chosen for all the three approaches based on the high R^2 value. Notably that the all the three models have no constant since if the amount of total available water, irrigation application and PPET is zero, no yield will be produced.

Yield-TW model

The first model is corn yield as a function of TW. Equation 6 shows the regression model.

$$Y_{corn} = 10.755*TW -0.138*TW^2 \qquad (6)$$

The Marginal Physical Product of TW in corn yield (MPPTW) is equal to the firstderivative of corn yield with respect to TW. The Marginal Value Product of TW (MVPTW) is obtained by multiplying the MPPTW by the price of corn (Pcorn) (Equation 7).

$$MVPTW = (10.755 -0.276*TW)*P_{corn} \qquad (7)$$

By equating MVPTW to MFC, the optimal levels of TW will be determined in relation to the price of corn and natural gas (Equation 8). Table 3 shows the optimal levels of TW by inserting the price range of corn and natural gas.

$$TW = \frac{1.08 * P_{NG} + 5.66 - 10.755 * P_{corn}}{-0.276 * P_{corn}} \qquad (8)$$

The maximized profit levels are obtained by subtracting the total cost from the total revenue. The variable cost regarding the level of irrigation application is obtained by subtracting the amount of average rainfall and soil water from the optimum level of total available water in order to determine the amount of water required from applying irrigation. The average amount of rainfall and soil water is estimated to be 10 inches for corn production which is obtained by subtracting average irrigation from average total available water in the project budget for corn (table 1). The levels of corn profit at each optimum level of total available water under the same ranges of natural gas and corn prices are shown in table 4.

Yield-Irrigation model

The corn yield-irrigation response function is developed by inserting the coefficients generated in this model (table 1), which is shown in Equation 9.

$$Y_{corn} = 15.809*I - 0.287*I^2 \qquad (9)$$

MPP_I and MVP_I could be obtained based on the Equation 9 and MVP_I is shown in Equation 10. Then the profit maximizing levels of irrigation application for corn could be determined by setting MFC equal to MVP_I. The optimal levels of irrigation application could be calculated under different prices of corn (P_{corn}) and natural gas (P_{NG}) (Equation 11).

$$MVP_I = (-0.574*I+15.809)*P_{corn} \tag{10}$$

$$I = \frac{1.08*P_{NG}+5.66-15.809*P_{corn}}{-0.574*P_{corn}} \tag{11}$$

By solving Equation 11 with applying assumed price range of corn price and natural gas, the optimum level of irrigation application could be determined which is shown in Table 5.

The variable cost regarding irrigation application for corn is obtained by multiplying the optimum levels of irrigation application with per unit irrigation variable cost. The levels of corn profit at each optimum level of irrigation application under the same ranges of natural gas and corn price are shown in table 6.

Yield-PPET model

The yield-PPET response function for corn is developed by inserting the coefficients generated in the corresponding model, shown in Equation 12.

$$Y_{corn} = 3.475*PPET - 0.014*PPET^2 \tag{12}$$

In order to reflect the PPET-TW relation, a linear regression model is used to predict PPET as a function of TW which is shown in Equation 13.

$$PPET=18.734+2.216*TW \qquad (13)$$

Based on the production function, MPP_{PPET}(Equation 14) and MVP_{PPET} (Equation 15) could be determined. Here MPP_{PPET} requires two steps to calculate according to the chain rule. Frist taking the first derivative of Y_{corn} with respect to PPET and the first derivative of PPET with respect to TW, and then multiply them together. Next, the profit maximizing levels of PPET for corn could be determined by equating MFC to MVP_{PPET}. Thus, applying assumed prices of corn (P_{corn}) and natural gas (P_{NG}), the optimal levels of PPET could be calculated (Equation 16). Table 7 illustrates the optimum levels of PPET by applying the assumed corn and natural gas price ranges to Equation 16.

$$MPP_{PPET}=\frac{d\,Y_{corn}}{d\,PPET}*\frac{d\,PPET}{d\,TW}=(-0.028*PPET+3.475)*2.216=-0.062*PPET+7.701 \qquad (14)$$

$$MVP_{PPET}=(-0.062*PPET+7.701)*P_{corn} \qquad (15)$$

$$PPET=\frac{1.08*P_{NG}+4.6-7.701*P_{corn}}{-0.062*P_{corn}} \qquad (16)$$

It needs to remind that the variable cost regarding the level of irrigation is obtained by subtracting the amount of average rainfall and soil water from the optimum level of TW which meets PPET in order to determine the amount of water required from applying irrigation. The sum of the amount of rainfall and soil water is estimated to be 10 inches as under total available water approach of corn.

The level of corn profit at each optimum level of TW to meet PET applying alternative combination of natural gas and corn price is shown in table 8.

Benefit Analysis of PET

As introduced earlier, PET is the amount of water that a well-grown plant exactly needs. If 100% of PET is satisfied, theoretically the water condition should be optimum for the plants. As putting more water to meet 100% of PET, producers are expecting more profit. In order to explore the trade-off between the extra irrigation input and the extra profit, the results are analyzed in a further step.

Table 7 shows the marginal profit per acre-inch of irrigation at different PPET levels under corn price of $5/bushel and natural gas price of $2.5/mcf. It shows a decrease of marginal profit as the PPET level increases. For example, when the total water could meet 10% more PET from 60% to 70%, the marginal profit, which is the added profit realized by meeting this 10% more PET, is around $15. While, when this figure increases to 80% from 70%, the same amount of irrigation just makes $11 more per acre.

Even though a decreasing marginal profit will be realized, producers are still willing to keep irrigating to meet 100% of PET since the total profit keeps increasing. PPET information, however, could be used by policy makers in the water allocation decision-making process regarding irrigation. For example, in order to preserve the water resource, some kind of subsidy could be granted to irrigators which requires them agree on a certain limitation of water use in irrigation. In this way, the subsidy makes up the profit gap due to different levels of irrigation application that producers are encountered and to some degree the water resource could be conserved.

Conclusions

Corn is the intensive water-use crop in the Texas Panhandle area. Due to the important role irrigation has played in the regional economy of this area, this study analyzes corn production under three water approaches including total available water (TW), irrigation application and Percent of Potential Evapotranspiration (PPET) to determine the optimal production decisions regarding these approaches. The producers only have control over the amount of the irrigation application while the irrigation level could affect the amount of total available water and PPET.

The optimum levels of TW, irrigation application and PPET for corn range from 23.53 to 32.25 acre inches, 20.12 to 25.75 acre inches and 55.42% to 107.57% respectively when corn is sold at \$3/bushel to \$7.5/bushel. Based on the economic results, benefit analysis is conducted and it proves that the use of PET information could help improve the water conservation decision-making process.

While for the future study, more detailed analysis of PPET should be included. For example, determine the PPET levels at certain growth stages. Also, irrigation timing should be a variable being taken into consideration in such analysis. By adding irrigation timing, the economic results regarding PPET may not show as much unrealistic as this study which will help make the result more precise and more useful in directing the real production.

References

[1] Almas, L.K., F. Bretz, S. Amosson, T. Marek, L. New, and B. Stewart. *Determining Region A Water Supply Needs for the 50-year Planning Period.* Panhandle Water Planning Project Task 4 Project Memorandum. Texas A&M University, Agricultural Research and Extension Center, Amarillo, Texas, April 2000.

[2] Amosson, S.H., L. Almas, F. Bretz, D. Gaskins, B. Guerrero, D. Jones, T. Marek, L. New and N. Simpson. 2006. Water Management Strategies for Reducing Irrigation Demands in Region A. Senate Bill 2 Research Report prepared for Agricultural Subcommittee of Panhandle Water Planning Group, Panhandle Water Planning Project Task 4, Texas A&M University AREC, Amarillo, Texas. June 30, 2005.

[3] Colaizzi, P.D., P. Gowda, T. Marek and D. Porter. 2008. Irrigation in the Texas High Plains: a brief history and potential reductions in demand. *Irrigation and Drainage*. 58: 257-274

[4] Colette, W.A. and L.Almas. 2004. Estimating the MVP and Optimum Irrigation Level for Grain Sorghum Utilizing Evapotranspiration Requirements for the Texas Panhandle. American Agricultural Economics Association Annual Meeting, Denver, CO, August 1-4, 2004.

[5] Colette, W.A. and L. Almas. 2007. Comparison of Water Allocation Strategies for Wheat Production in the Texas Panhandle. Southern Agricultural Economics Association Annual Meeting, Mobile, Alabama, February 3-6, 2007.

[6] Colette, W.A., L. Almas and C. Robison. 2008. The Use of Weather Data and Evapotranspiration Requirements to Estimate the Marginal Value Product of Irrigation and the Profit Maximizing Irrigation Level for Corn in the Texas Panhandle. Southern Agricultural Economics Association (SAEA) Annual Meetings, Dallas, Texas.

[7] Marek T.H., T. Howell, L. New, B. Bean, D. Dusek and G. Michels, Jr. 1996. Texas North Plains PET Network.

[8] McGuire, V.L. 2011.Water-Level Changes in the High Plains Aquifer, Predevelopment to 2009, 2007–08, and 2008–09, and Change in Water in Storage, Predevelopment to 2009. U.S. Geological Survey, Reston, Virginia: 201, Revised December 2011.

[9] Rogers, D.H. and M. Alam. 2007. What is ET? Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan, Kansas.

[10] State Agriculture Overview. 2010. USDA's NASS Texas Field Office, the Texas Department of Agriculture.

Table 1 Change in water in storage (million acre-feet) in the High Plain aquifer, pre development to 2009 by selected state

State	Water storage change (million acre-feet)
Colorado	-19.40
Kansas	-64.70
Nebraska	-16.60
New Mexico	-11.40
Oklahoma	-13.00
South Dakota	-0.50
Texas	-144.50
Wyoming	-2.60

Table 2: Summary of regression outputs

Water Approach		TW	Irrigation	PPET	
Model		Yield-TW	Yield-Irrigation	Yield-PPET	PPET-TW
R^2		0.963	0.957	0.968	0.649
Significance F		0	0	0	0
Coefficients	Intercept	0	0	0	18.734
	X variable 1	10.755	15.809	3.475	2.216
	X variable 2	-0.138	-0.287	-0.014	-

Table 3: Optimum level of total available water (acre-inch) for corn under alternative combinations of corn and natural gas price

P_{NG} ($/mcf)	P_{corn} ($/bushel)									
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**
2	29.67	31.00	32.00	32.77	33.39	33.90	34.32	34.68	34.98	35.25
2.5	29.06	30.47	31.54	32.36	33.02	33.56	34.01	34.39	34.72	35.00
3	28.44	29.95	31.07	31.95	32.65	33.23	33.71	34.11	34.46	34.76
3.5	27.83	29.42	30.61	31.54	32.28	32.89	33.40	33.83	34.19	34.51
4	27.21	28.89	30.15	31.13	31.92	32.56	33.09	33.54	33.93	34.27
4.5	26.60	28.37	29.69	30.72	31.55	32.22	32.78	33.26	33.67	34.02
5	25.98	27.84	29.23	30.31	31.18	31.89	32.48	32.98	33.40	33.77
5.5	25.37	27.31	28.77	29.90	30.81	31.55	32.17	32.69	33.14	33.53
6	24.75	26.79	28.31	29.49	30.44	31.22	31.86	32.41	32.88	33.28
6.5	24.14	26.26	27.85	29.08	30.07	30.88	31.55	32.12	32.61	33.04
7	23.53	25.73	27.39	28.67	29.70	30.54	31.25	31.84	32.35	32.79

Table 4: Profit Maximization ($/acre) of corn at optimum level of total available water under alternative combinations of corn and natural gas price

P_{NG} ($/mcf)	P_{corn} ($/bushel)									
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**
2	0.86	100.53	201.47	303.26	405.65	508.47	611.62	715.02	818.62	922.37
2.5	-8.99	89.97	190.39	291.78	393.84	496.40	599.32	702.53	805.97	909.58
3	-18.54	79.69	179.55	280.50	382.22	484.49	587.18	690.19	793.45	896.91
3.5	-27.77	69.67	168.94	269.43	370.78	472.75	575.19	677.99	781.07	884.37
4	-36.69	59.92	158.56	258.57	359.53	461.18	563.36	665.93	768.82	871.96
4.5	-45.29	50.43	148.42	247.92	348.47	449.79	551.68	654.02	756.71	859.67
5	-53.58	41.22	138.52	237.48	337.60	438.56	540.17	642.26	744.73	847.51
5.5	-61.56	32.27	128.85	227.24	326.91	427.51	528.80	630.63	732.88	835.47
6	-69.23	23.60	119.41	217.22	316.41	416.63	517.60	619.16	721.17	823.56
6.5	-76.58	15.19	110.21	207.40	306.10	405.91	506.55	607.82	709.59	811.77
7	-83.62	7.05	101.24	197.79	295.98	395.37	495.66	596.63	698.15	800.10

Table 5: Optimum level of irrigation application (acre-inch) for corn under alternative combinations of corn and natural gas price

P_{NG} ($/mcf)	P_{corn} ($/bushel)									
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**
2	23.07	23.71	24.19	24.56	24.86	25.10	25.31	25.48	25.63	25.75
2.5	22.78	23.46	23.97	24.37	24.68	24.94	25.16	25.34	25.50	25.64
3	22.48	23.20	23.75	24.17	24.51	24.78	25.01	25.21	25.37	25.52
3.5	22.19	22.95	23.52	23.97	24.33	24.62	24.86	25.07	25.25	25.40
4	21.89	22.70	23.30	23.77	24.15	24.46	24.72	24.93	25.12	25.28
4.5	21.59	22.44	23.08	23.58	23.97	24.30	24.57	24.80	24.99	25.16
5	21.30	22.19	22.86	23.38	23.80	24.14	24.42	24.66	24.87	25.04
5.5	21.00	21.94	22.64	23.18	23.62	23.98	24.27	24.52	24.74	24.93
6	20.71	21.68	22.42	22.99	23.44	23.81	24.12	24.39	24.61	24.81
6.5	20.41	21.43	22.19	22.79	23.26	23.65	23.98	24.25	24.49	24.69
7	20.12	21.18	21.97	22.59	23.09	23.49	23.83	24.11	24.36	24.57

Table 6: Profit Maximization ($/acre) of corn at optimum level of irrigation application under alternative combinations of corn and natural gas price

P_{NG} ($/mcf)	P_{corn} ($/bushel)									
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**
2	17.74	124.13	231.14	338.56	446.27	554.18	662.25	770.44	878.73	987.09
2.5	6.07	112.13	218.89	326.11	433.66	541.45	649.41	757.51	865.72	974.01
3	-5.45	100.25	206.74	313.76	421.14	528.79	636.64	744.64	852.77	960.99
3.5	-16.82	88.51	194.71	301.51	408.71	516.22	623.95	731.85	839.89	948.03
4	-28.03	76.89	182.80	289.36	396.37	503.73	611.33	719.12	827.07	935.14
4.5	-39.10	65.40	170.99	277.31	384.13	491.32	598.79	706.47	814.32	922.30
5	-50.02	54.04	159.30	265.35	371.97	478.99	586.32	693.88	801.63	909.52
5.5	-60.78	42.81	147.72	253.50	359.90	466.75	573.93	681.36	789.00	896.80
6	-71.40	31.71	136.25	241.75	347.93	454.58	561.61	668.91	776.44	884.14
6.5	-81.86	20.74	124.90	230.10	336.04	442.50	549.37	656.54	763.95	871.55
7	-92.18	9.89	113.66	218.56	324.24	430.51	537.20	644.23	751.51	859.01

Table 7: Optimum level of Percent of PET (%) for corn under alternative combinations of corn and natural gas price

P_{NG} ($/mcf)	P_{corn} ($/bushel)									
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**
2	82.76	88.67	93.10	96.54	99.30	101.56	103.43	105.03	106.39	107.57
2.5	80.03	86.33	91.05	94.72	97.66	100.06	102.07	103.76	105.22	106.48
3	77.29	83.98	89.00	92.90	96.02	98.57	100.70	102.50	104.04	105.38
3.5	74.56	81.64	86.95	91.08	94.38	97.08	99.33	101.24	102.87	104.29
4	71.83	79.29	84.90	89.25	92.74	95.59	97.97	99.98	101.70	103.19
4.5	69.09	76.95	82.84	87.43	91.10	94.10	96.60	98.71	100.53	102.10
5	66.36	74.61	80.79	85.61	89.46	92.61	95.23	97.45	99.36	101.01
5.5	63.62	72.26	78.74	83.78	87.82	91.12	93.86	96.19	98.18	99.91
6	60.89	69.92	76.69	81.96	86.18	89.62	92.50	94.93	97.01	98.82
6.5	58.15	67.57	74.64	80.14	84.53	88.13	91.13	93.67	95.84	97.73
7	55.42	65.23	72.59	78.31	82.89	86.64	89.76	92.40	94.67	96.63

Table 8: Profit Maximization ($/acre) of corn at optimum level of total available water to meet PET under alternative combinations of corn and natural gas price

P_{NG} ($/mcf)	P_{corn} ($/bushel)									
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**
2	-10.90	86.66	186.79	288.62	391.65	495.56	600.11	705.17	827.40	916.39
2.5	-20.20	75.96	175.03	276.05	378.43	481.79	585.90	690.58	814.79	901.20
3	-28.88	65.79	163.75	263.89	365.58	468.37	572.01	676.29	802.59	886.26
3.5	-36.93	56.16	152.93	252.16	353.10	455.30	558.43	662.28	790.80	871.57
4	-44.34	47.07	142.59	240.84	341.01	442.56	545.16	648.56	779.43	857.14
4.5	-51.14	38.52	132.72	229.94	329.29	430.17	532.21	635.14	768.48	842.95
5	-57.30	30.51	123.32	219.46	317.94	418.12	519.57	622.00	757.95	829.02
5.5	-62.83	23.03	114.39	209.40	306.98	406.41	507.25	609.16	747.83	815.34
6	-67.74	16.10	105.93	199.76	296.39	395.05	495.24	596.60	738.12	801.91
6.5	-72.02	9.70	97.94	190.54	286.18	384.03	483.54	584.33	728.84	788.73
7	-75.67	3.84	90.43	181.73	276.34	373.35	472.16	572.36	719.97	775.80

Table 9 Benefit Analysis of PET for corn

PPET(%)	TW(acre-inch)	Irrigation (acre-inch)	yield (bushel)	Profit ($/acre)	Marginal profit ($/acre-inch irrigation)
100	35.70	25.70	207.50	386.01	3.21
90	32.13	22.13	199.35	374.55	7.13
80	28.56	18.56	188.40	349.10	11.05
70	24.99	14.99	174.65	309.64	14.97
60	21.42	11.42	158.10	256.18	