COMPARING PRODUCTION OPTIMIZATION STRATEGIES FOR TEXAS PANHANDLE PRODUCERS IN RESPONSE TO DECLINING WATER AVAILABILITY DUE TO DECLINE IN THE OGALLALA AQUIFER

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Abstract: In response to the declining availability of irrigation water from the Ogallala aquifer, irrigation at the level where MVP=MFC increases net returns over either irrigating to maximize production or meet 100% of the evapotranspiration (PET) requirements. This prolongs the economic life of the aquifer and increases the efficiency of irrigation.

Key Words: irrigation efficiency, water response function, input use optimization, ET.

Introduction: Irrigation is important to maintaining the agricultural productivity in the Texas Panhandle. The development and decline of irrigation in the region has occurred since the end of World War II. Between 1950 and 1980 irrigated acres increased from 19,315 to 1,754,560. Since 1980 irrigated acres have declined to 1,363,438. The water availability in the Ogalalla aquifer has declined and pumping costs have increased. Irrigation increases yield by 2 to 7 times over non-irrigation. When risk is defined as a function of the variability in yield, irrigation reduces risk by 75% to 90%.

The decline in the water level in the Ogallala aquifer is an on-going concern. Wells that produced 1000 to 1200 gallons per minute in the 1960's often produced less than 600 gallons per minute in the 1990's. Since there is 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 farming operation and reduces the returns to the resources held by the farmer (Amosson et al. 2001). In a recent discussion a leading Panhandle producer stated that his strategy was to determine the amount of water that he could pump during the growing season and then use it on the number of acres that would maximize his corn production. This led to an evaluation of water allocation strategies.

Objective: The objectives of this study are: 1) to estimate crop response functions for corn, sorghum, and wheat to determine the marginal value product of irrigation in each of the major crops; 2) to evaluate the net return from alternative water allocation criterion, and 3) evaluate these three alternative criterion in the context of declining water availability.

Data: Data utilized in this study was collected from 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. The date, number and amount of individual irrigations were recorded and calculated using well delivery gallons per minute and the number of acres irrigated. A rain gauge located at the site measured rainfall. Beginning and ending soil moisture readings were used to calculate net soil water depletion during the growing season. 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. The data includes 87 observation for corn, 50 observations for sorghum, and 111 observation for wheat.

Production costs: Crop production budgets for irrigated and nonirrigated corn, sorghum, and wheat for 2005 provided by the TAMU Cooperative Extension Service are used to estimate direct and fixed production costs. Irrigation is evaluated as the variable input with other input levels assumed constant. Only the cost of the irrigation is included as a variable cost. The direct and fixed cost are constant and independent of the amount of water applied. Since all irrigation in the region uses groundwater, the variable cost associated with irrigation is limited to pumping and application cost. Therefore, the variable input 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).

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

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.

Since natural gas is the predominate source of energy for pumping irrigation water in the area, natural gas is used in the calculation of fuel cost. The fuel cost (FULC) is equal to the product of the amount of fuel used (NG) multiplied by the price of the fuel (P_{NG}). In turn the amount of natural gas needed to pump and deliver one inch of water depends on the efficiency of the system, the lift required to get the water from below the ground to the delivery system, and the pressure of the delivery system (Equation 2).

$$NG = 0.0038*L + 0.0088*PSI - 0.000007623*PSI*L - 0.0000033*L^2 \quad (2)$$

Where:
NG is the mcf of natural gas
L is the system lift in feet
PSI is the system pressure per square inch

The NG, LMR, LC and AIC are known constants for a given irrigation system. (Almas 2000). The labor costs (LC) and the average investment cost (AIC) are included as per acre costs in the enterprise budgets and are therefore not included in this calculation. For example, the Total Cost function for a typical Low Energy Precision Application (LEPA) system with a 350 foot system lift can be expressed as Equation 3.

$$TC = FC + (1.018P_{NG} + 2.03)W \quad (3)$$

The Marginal Factor Cost of water (MFC_W) can now be calculated from the cost function. The MFC_W is the first derivative of the cost function with respect to the input, water (W) (Equation 4).

$$MFC_W = \frac{dC_W}{dW} \quad (4)$$

$$MFC_W = 1.018P_{NG} + 2.03$$

Estimation of response function, marginal value product, and economic optimum level of irrigation for corn: The quadratic response function relating the production of corn to the water available from natural precipitation, soil moisture, and supplemental irrigation provides the following model. The model has a $Pr>F_{(2,85)}=0.0038$ with an R^2 of 0.1232. Equation 5 reports the response function. The $Pr>t_{(85)}$ is in parentheses below the coefficients.

$$Y_C = \underset{0.9527}{248.933} + \underset{0.0365}{573.234W} - \underset{0.0858}{7.388W^2} \tag{5}$$

Where: Y_C is the production of corn grain in bu. per acre,
W is acre inches of available water.

The Marginal Physical Product of Water in corn production (MPP_{WC}) is equal to the derivative of the response function with respect to the input water. The Marginal Value Product of water in corn production (MVP_{WC}) is obtained by multiplying the Marginal Physical Product of water in corn production (MPP_{WC}) by the price of the product (P_C) (Equation 6).

$$\begin{aligned} MVP_{WC} &= MPP_{WC} * P_C \\ MVP_{WC} &= (573.234 - 14.776W)P_C \end{aligned} \tag{6}$$

The Optimum level of the input water application in corn production is determined by equating the Marginal Value Product of water (MVP_{WC}) from Equation 6 and the Marginal Factor Cost of water (MFC_W) from Equation 4. Solving for the level of available water (W) produces a function in the price of natural gas (P_{NG}) and the price of the corn (P_C) (Equation 7)

$$W = \frac{573.234 - \dfrac{1.018P_{NG} + 2.03}{P_C}}{14.776} \tag{7}$$

Optimal irrigation levels are derived from Equation 7 by subtracting the contribution from natural precipitation and soil moisture (9.84 ac. in.) from available water requirement. Optimum irrigation levels for natural gas prices between $4 and $12 per mcf and corn prices between $2 and $5 per bu. are shown in Table 1.

Estimation of response function, marginal value product, and economic optimum level of irrigation for sorghum: The quadratic response function relating the production of sorghum to the water available from natural precipitation, soil moisture, and supplemental irrigation provides the following model. The model has a $Pr>F_{(2,47)}=4.614E-09$ with an R^2 of 0.5581. The response function is reported in Equation 8. The $Pr>t_{(47)}$ is in parentheses below the coefficients.

$$Y_S = -\underset{0.0400}{4707.904} + \underset{0.0005}{756.083}W - \underset{0.0123}{11.105}W^2 \qquad (8)$$

Where: Y_S is the production of sorghum grain in lbs. per acre,
W is acre inches of available water.

The Marginal Physical Product of Water in Sorghum (MPP_{WS}) is equal to the derivative of the response function with respect to the input water. The Marginal Value Product of water in sorghum production (MVP_{WS}) is obtained by multiplying the Marginal Physical Product of water in sorghum production (MPP_{WS}) by the price of the product (P_S) (Equation 9).

$$\begin{aligned} MVP_{WS} &= MPP_{WS} * P_S \\ MVP_{WS} &= (756.083 - 22.210W)P_S \end{aligned} \qquad (9)$$

The Optimum level of the input water application in sorghum production is determined by equating the Marginal Value Product of water (MVP_{WS}) from Equation 9 and the Marginal Factor Cost of water (MFC_W) from Equation 4. Solving for the level of available water (W) produces a function in the price of natural gas (P_{NG}) and the price of the sorghum (P_S) (Equation 10).

$$W = \frac{756.083 - \frac{1.018P_{NG} + 2.03}{P_S}}{22.210} \tag{10}$$

Optimal irrigation levels are derived from Equation 10 by subtracting the contribution of natural precipitation and soil moisture (11.01 ac. in.) from optimum available water. Profit maximizing irrigation level for natural gas prices between $4 and $12 per mcf and sorghum prices between $2.50 and $5.50 per cwt are shown in Table 2.

Estimation of response function, marginal value product, and economic optimum level of irrigation for wheat: Winter wheat production in the Texas Panhandle provides joint products: grain and grazing. A quadratic response function is estimated to relate the production of wheat grain to the water available from natural precipitation, soil moisture, and supplemental irrigation. The model has a $Pr>F_{(2,108)}$=1.07E-12 with an R^2 of 0.3998. The estimated response function is shown in Equation 11. The $Pr>t_{(108)}$ is in parentheses below the coefficients.

$$Y_W = \underset{0.1965}{-15.772} + \underset{7.65E\text{-}06}{6.680W} - \underset{0.0056}{0.113W^2} \tag{11}$$

Where: Y_W is the production of wheat grain in bu. per acre,
W is acre inches of available water.

The Marginal Physical Product of Water in wheat grain (MPP_{WW}) is equal to the derivative of the response function with respect to the input water. The Marginal Value Product of water in wheat production (MVP_{WW}) is obtained by multiplying the Marginal Physical Product of water in wheat grain production (MPP_{WW}) by the price of wheat (P_W) (Equation 12).

$$MVP_{WW} = MPP_{WW} * P_W \tag{12}$$
$$MVP_{WW} = (6.680 - 0.226W)P_W$$

A Spillman exponential-type response function adapted from Heady and Candler is used to estimate the response of wheat grazing to the availability of water, Equation 13.

$$Y_{WG} = M - AR^W \tag{13}$$

Where:

Y_{WG} is the number of cwt grazing days,
M is the maximum cwt days that can provided by irrigation,
A is the total increase in cwt grazing days due to irrigation,
R is a constant ratio of successive increments of total product, and
W is the level of irrigation in ac. in.

The Marginal Physical Product of wheat grazing is the first derivative of the response function with respect to water, Equation 14.

$$MPP_{WG} = -AR^W lnR \tag{14}$$

$$MPP_{WG} = 270*0.8^W*0.22314$$

The Marginal Value Product of grazing is equal to the Marginal Physical Product multiplied by the Price of wheat (P_W). The Marginal Value Product of Water in the Production of the joint products, grain and grazing is the sum of the marginal value products.

$$MVP_W = (6.680 - 0.226W + 60.2488*0.8^W)*P_W \tag{15}$$

The Optimum level of the input water application in wheat production is determined by equating the Marginal Value Product of water in wheat production (MVP_W) from Equation 15 and the Marginal Factor Cost of water (MFC_W) from Equation 4.

$$MVP_W = MFC_W \tag{16}$$

$$(6.680 – 0.226W + 60.2488*0.8W) *P_W= 1.018P_{NG} + 4.63$$

This equation can be solved by iteration using Solver in Microsoft Excel. Optimal water availability for natural gas prices between $4 and $12 per mcf and wheat prices between $2.50 and $5.50 per bu. are shown in Table 3.

Results and Discussion: The quadratic response function for corn is estimated from 87 observations of commercial corn producers cooperating in the Agripartners project between 1998 and 2003. The function indicated that the expected value of irrigation that will maximize corn production is 28.95 ac. in. of water with an expected yield of 203 bu. The mean calculated 100% PET level is 25.96 ac. in. of irrigation with a yield of 201.8. This indicates that it required approximately three acre inches of water to get that last 1.2 bushels of corn. Given current prices of $3 per bushel for corn and $6 per mcf for natural gas, profit is maximized if the producer applies 18.67 ac. in. of irrigation with a yield of 189 bu. per ac. Profit maximizing irrigation levels and net return to land and irrigation for corn prices from $2 to $5 per bu. and natural gas prices from $4 to $12 per mcf are reported in Table 1. The expected irrigation level and expected net return represents a LEPA or LESA system with a 350 foot lift for each combination of corn and natural gas prices. The optimum irrigation level and net return increases as the price of corn increases and decreases as the price of natural gas increases.

The quadratic response function for sorghum is estimated from 50 observations of commercial sorghum producers cooperating in the Agripartners project between 1998 and 2003. The function indicated that the expected value of irrigation that will maximize sorghum production is 23.03 ac. in. of water with a yield of 81.6 cwt. The mean calculated 100% PET level is 16.01 ac. in of irrigation with a yield of 76.1 cwt. This indicates that it required approximately 7 ac. ins. of water to get that last 5 cwt of sorghum. Given current prices of $4.50 per cwt for sorghum and $6 per mcf for natural gas, profit is maximized if the producer applies

14.89 ac. in of irrigation with a yield goal of 72 cwt. per ac. Profit maximizing irrigation levels and net return to land and irrigation for sorghum prices from $2.50 to $5.50 per cwt. and natural gas prices from $4 to $12 per mcf are reported in Table 2. The expected irrigation level and expected net return is estimated for a LEPA or LESA system with a 350 foot lift for each combination of sorghum and natural gas prices. The optimum irrigation level and net return increases as the price of sorghum increases and decreases as the price of natural gas increases.

Wheat production produces grain and winter grazing as joint products. A quadratic response function for wheat grain is estimated from 111 observations of commercial wheat producers cooperating in the Agripartners project between 1998 and 2003. The function indicated that the expected value of irrigation that will maximize wheat grain production is 18.98 ac. in. of water. The yield associated with this level of irrigation is 83 bu.. The mean calculated 100% PET level is 11.72 ac. in of irrigation with a yield of 77.1 bu. This indicates that it required approximately 7 acre inches of water to get that last 6 bu. of wheat . Given current prices of $3 per bu. for wheat and $6 per mcf for natural gas, profit is maximized if the producer applies 8.79 ac. in of irrigation with a yield goal of 71.3 bu. per ac.

The relationship between irrigation and grazing winter wheat is expressed by a Spillman exponential-type function. Production levels are measured in grazing days per cwt of animal Grazing production ranges from 50 cwt days without irrigation to 320 cwt days per acre under full irrigation. Price for grazing is set a $0.15 per cwt day. This translates to $0.60 per day for a 400 lb stocker. Profit maximizing irrigation levels and net return to land and irrigation for wheat prices from $2.50 to $5.50 per bu. and natural gas prices from $4 to $12 per mcf are reported in Table 3. The expected irrigation level and expected net return is estimated for a LEPA or LESA system with a 350 foot lift for each combination of sorghum and natural gas prices. The optimum irrigation level and net return increases as the price of sorghum increases and decreases as the price of natural gas increases.

The introduction and expansion of irrigation in the Texas Panhandle dates from the 1950s and ‘60s. At that time natural gas, the main energy source for pumping, cost less than $0.25 so that variable irrigation costs were so low that producers based their decision on irrigation level on maximizing profits. The loss due to the over use of the resource was so small that it was considered good insurance to apply more than was necessary. During the past decade producers have become extremely sensitive to the decline in the productivity of the wells pumping from the Ogallala aquifer and the increased energy cost associated with irrigation.

Three irrigation decision strategies are analyzed for the three major crops grown in the area, Table 4. The three decision alternatives are: 1) irrigate to maximize production, 2) irrigate to satisfy 100% of the needs of the growing crop as indicated by the potential evapotranspiration (PET), and 3) irrigate to the point where Marginal Value Product equals Marginal Factor Cost and profit is maximized. The net return from corn dominates the irrigated crop activities. Under all three decision criterion corn provides the highest net return. The net return from corn is negative when production per acre is maximized and increases as the irrigation decision approaches the profit maximizing level. Adopting the criterion of irrigating to meet 100% of PET reduces irrigation by 3 ac. in per acre but increases net return from $-1.37 to $19.41. Under the profit maximizing criterion, irrigation is reduced by another 7 ac. in. while the net return more than doubles to $40.42 per acre.

Although both irrigated sorghum and irrigated wheat activities are dominated by irrigated corn, they follow the same pattern of net returns in response to the irrigation criterion. The lowest net return is received when the goal is to maximize yield. Net return increases as the irrigation goal shifts to providing 100% of the plant needs. But the highest net return is achieved in each case is obtained when the goal is to irrigate to the level where MVP is equal to MFC.

The Base Scenario assumes 1,000 acres of cropland and sufficient water to irrigate at a level to maximize output, Table 5. Producing 1,000 acres of irrigated corn provides the highest return under all three decision criterion. However, irrigating at the profit maximizing level reduces water use by more than 10,000 ac. in. and increases net return from $-1,373 to $40,419. Even when there is no rationing of water, net returns are maximized when irrigation is reduced to the level where the Marginal Value Product of Water equals to Marginal Factor Cost of applying the water.

Under the second scenario the availability of water is reduced by 20% to 23,160 ac. in., Table 6. This is inline with the goal to Texas Senate Bill 1 which specifies planning so that no more than 50% of the water in the Ogallala aquifer will be depleted by the year 2050. Under this scenario, the highest net returns are achieved when all the irrigation water is applied to corn production and residual acres are planted to nonirrigated wheat. If irrigation is applied to maximize the production of corn, then 800 acres of corn and 200 acres of dryland wheat can be produced. This utilized all of the available water, but the combined net return is only $310. Irrigating to meet 100% of the crop water needs as indicated by PET results in 892 acres of corn and 108 acres of nonirrigated wheat. All of the available water is used and the total net return is increased to $18, 076. Even with the 20% reduction in water availability, there is sufficient water available to irrigate the entire 1,000 acres in corn when irrigation is applied at the profit maximizing level. Only 18,640 ac. in. of water are required and net return is maintained at $40,419.

Under the third scenario, water availability is reduced by 40% to 17,370 ac. ins., Table 7. Irrigated corn remains the dominate strategy under this restricted water availability. If irrigation is applied to maximize yield per acre, 600 acres of corn and 400 acres of nonirrigated wheat can be produced. The total net return is only $1,994 with the positive net return from the wheat offset by the negative net return from the irrigated corn. Irrigating to meet 100% of the crop evapotranspiration requirements will allow the production of 669 acres of irrigated corn and 331 acres of nonirrigated wheat. The total net return is increased to $15,318. The best alternative is to choose the irrigation level corresponding to profit maximization. With the irrigation level set where Marginal Value Product equals Marginal Factor Cost, 930 acres of irrigated corn can be produced. The remaining 70 acres should be allocated to wheat. All of the water available during the summer growing season is utilized with the corn production. Two alternatives may be available for the wheat. The wheat may be produced with no irrigation, or since the same physical plant can provide additional water by pumping during the winter season the 70 acres of winter wheat can also be irrigated. The net return for these two alternatives is $38,089 with nonirrigated wheat and $38,360 with the irrigated alternative.

Current crop and natural gas prices are used in this analysis. The specific values will change as the relative input and product prices vary. However, the principle remains the same. Net return will be maximized when the irrigation is applied at the rate where marginal value product is equal to marginal factor cost. This result is consistent with the observation of local producer who expanded or contracted acreages of corn to utilize all of the available water. If the irrigation is applied to those acres at the level where marginal value product equals marginal factor cost, then this would be a profit maximizing solution. If the irrigation is applied so as to maximize corn yield per acre it would result in wasting a value resource and reducing net return.

Table 1a. Profit Maximizing Level of Irrigation in Acre-Inches under Various Corn and Natural Gas Prices in the Texas Panhandle*.

P_{NG} ($/mcf)	Price of Corn ($/bu)												
	2.00	**2.25**	**2.50**	**2.75**	**3.00**	**3.25**	**3.50**	**3.75**	**4.00**	**4.25**	**4.50**	**4.75**	**5.00**
4.00	17.4	18.7	19.7	20.5	21.2	21.8	22.3	22.8	23.2	23.5	23.8	24.1	24.3
4.50	16.4	17.8	18.9	19.8	20.6	21.2	21.8	22.3	22.7	23.1	23.4	23.7	23.9
5.00	15.5	17.0	18.2	19.1	20.0	20.7	21.2	21.8	22.2	22.6	23.0	23.3	23.6
5.50	14.5	16.1	17.4	18.4	19.3	20.1	20.7	21.2	21.7	22.2	22.5	22.9	23.2
6.00	13.5	15.2	16.6	17.7	18.7	19.5	20.1	20.7	21.2	21.7	22.1	22.5	22.8
6.50	12.6	14.4	15.8	17.0	18.0	18.9	19.6	20.2	20.8	21.2	21.7	22.1	22.4
7.00	11.6	13.5	15.1	16.3	17.4	18.3	19.0	19.7	20.3	20.8	21.2	21.6	22.0
7.50	10.6	12.7	14.3	15.6	16.7	17.7	18.5	19.2	19.8	20.3	20.8	21.2	21.6
8.00	9.7	11.8	13.5	14.9	16.1	17.1	17.9	18.7	19.3	19.9	20.4	20.8	21.2
8.50	8.7	11.0	12.8	14.2	15.5	16.5	17.4	18.2	18.8	19.4	20.0	20.4	20.9
9.00	7.7	10.1	12.0	13.5	14.8	15.9	16.8	17.6	18.4	19.0	19.5	20.0	20.5
9.50	6.8	9.2	11.2	12.8	14.2	15.3	16.3	17.1	17.9	18.5	19.1	19.6	20.1
10.00	5.8	8.4	10.4	12.1	13.5	14.7	15.7	16.6	17.4	18.1	18.7	19.2	19.7
10.50	4.9	7.5	9.7	11.4	12.9	14.1	15.2	16.1	16.9	17.6	18.2	18.8	19.3
11.00	3.9	6.7	8.9	10.7	12.2	13.5	14.6	15.6	16.4	17.2	17.8	18.4	18.9
11.50	2.9	5.8	8.1	10.0	11.6	12.9	14.1	15.1	15.9	16.7	17.4	18.0	18.5
12.00	2.0	5.0	7.4	9.3	11.0	12.3	13.5	14.6	15.5	16.3	17.0	17.6	18.2

*** - Optimum level of available water adjusted for natural precipitation during the growing season and soil water extraction (9.84 ac. in.)**

Table 1b. Net Return to Land and Irrigation when Applying Irrigation to Maximize Profits under Various Corn and Natural Gas Prices in the Texan Panhandle. ($ per acre)

P_{NG} ($/mcf)	Price of Corn ($/bu)												
	2.00	**2.25**	**2.50**	**2.75**	**3.00**	**3.25**	**3.50**	**3.75**	**4.00**	**4.25**	**4.50**	**4.75**	**5.00**
4.00	-110.2	-63.4	-15.7	32.4	81.1	130.0	179.2	228.6	278.2	327.9	377.7	427.7	477.7
4.50	-118.8	-72.6	-25.6	22.2	70.4	119.0	168.0	217.1	266.5	316.0	365.7	415.5	465.4
5.00	-126.9	-81.5	-35.0	12.2	60.1	108.4	157.0	205.9	255.1	304.4	353.9	403.5	453.3
5.50	-134.5	-89.9	-44.1	2.7	50.1	98.0	146.3	195.0	243.9	293.0	342.3	391.8	441.4
6.00	-141.7	-97.9	-52.7	-6.5	40.4	88.0	135.9	184.3	233.0	281.9	331.0	380.3	429.7
6.50	-148.3	-105.4	-61.0	-15.4	31.1	78.2	125.8	173.9	222.3	270.9	319.8	368.9	418.2
7.00	-154.5	-112.5	-68.8	-23.9	22.1	68.7	116.0	163.7	211.8	260.2	308.9	357.8	406.9
7.50	-160.1	-119.2	-76.3	-32.0	13.4	59.6	106.4	153.8	201.6	249.8	298.2	346.9	395.8
8.00	-165.3	-125.4	-83.4	-39.8	5.0	50.7	97.2	144.2	191.7	239.5	287.7	336.2	384.9
8.50	-170.0	-131.2	-90.1	-47.2	-3.0	42.2	88.2	134.8	182.0	229.5	277.5	325.7	374.2
9.00	-174.2	-136.6	-96.4	-54.3	-10.7	33.9	79.5	125.7	172.5	219.8	267.4	315.4	363.6
9.50	-177.9	-141.5	-102.3	-61.0	-18.1	26.0	71.0	116.9	163.3	210.2	257.6	305.3	353.3
10.00	-181.1	-146.0	-107.8	-67.3	-25.1	18.4	62.9	108.3	154.3	200.9	248.0	295.4	343.2
10.50	-183.8	-150.1	-112.9	-73.3	-31.9	11.0	55.0	99.9	145.6	191.8	238.6	285.7	333.3
11.00	-186.0	-153.7	-117.7	-79.0	-38.3	4.0	47.4	91.9	137.1	183.0	229.4	276.3	323.5
11.50	-187.7	-156.9	-122.0	-84.3	-44.3	-2.8	40.1	84.1	128.9	174.4	220.4	267.0	314.0
12.00	-189.0	-159.6	-125.9	-89.2	-50.1	-9.2	33.1	76.5	120.9	166.0	211.7	258.0	304.7

Table 2a. Profit Maximizing Level of Irrigation in Acre-Inches under Various Sorghum and Natural Gas Prices in the Texas Panhandle*.

P_{NG} ($/mcf)	Price of Sorghum ($/cwt)												
	2.50	**2.75**	**3.00**	**3.25**	**3.50**	**3.75**	**4.00**	**4.25**	**4.50**	**4.75**	**5.00**	**5.25**	**5.50**
4.00	12.0	13.0	13.9	14.6	15.2	15.7	16.2	16.6	16.9	17.2	17.5	17.8	18.0
4.50	11.1	12.2	13.1	13.9	14.5	15.1	15.6	16.0	16.4	16.8	17.1	17.4	17.6
5.00	10.2	11.4	12.3	13.2	13.9	14.5	15.0	15.5	15.9	16.3	16.6	16.9	17.2
5.50	9.3	10.5	11.6	12.5	13.2	13.9	14.4	15.0	15.4	15.8	16.2	16.5	16.8
6.00	8.4	9.7	10.8	11.8	12.6	13.3	13.9	14.4	14.9	15.3	15.7	16.1	16.4
6.50	7.5	8.9	10.1	11.1	11.9	12.7	13.3	13.9	14.4	14.8	15.2	15.6	16.0
7.00	6.5	8.0	9.3	10.3	11.3	12.0	12.7	13.3	13.9	14.4	14.8	15.2	15.5
7.50	5.6	7.2	8.5	9.6	10.6	11.4	12.2	12.8	13.4	13.9	14.3	14.7	15.1
8.00	4.7	6.4	7.8	8.9	9.9	10.8	11.6	12.3	12.9	13.4	13.9	14.3	14.7
8.50	3.8	5.5	7.0	8.2	9.3	10.2	11.0	11.7	12.3	12.9	13.4	13.9	14.3
9.00	2.9	4.7	6.2	7.5	8.6	9.6	10.4	11.2	11.8	12.4	13.0	13.4	13.9
9.50	2.0	3.9	5.5	6.8	8.0	9.0	9.9	10.6	11.3	11.9	12.5	13.0	13.5
10.00	1.0	3.0	4.7	6.1	7.3	8.4	9.3	10.1	10.8	11.5	12.0	12.6	13.0
10.50	0.1	2.2	3.9	5.4	6.7	7.8	8.7	9.6	10.3	11.0	11.6	12.1	12.6
11.00	0.0	1.4	3.2	4.7	6.0	7.2	8.1	9.0	9.8	10.5	11.1	11.7	12.2
11.50	0.0	0.5	2.4	4.0	5.4	6.5	7.6	8.5	9.3	10.0	10.7	11.3	11.8
12.00	0.0	0.0	1.7	3.3	4.7	5.9	7.0	7.9	8.8	9.5	10.2	10.8	11.4

*** - Optimum level of available water adjusted for natural precipitation during the growing season and soil water extraction (11.01 ac. in.)**

Table 2b. Net Return to Land and Irrigation when Applying Irrigation to Maximize Profits under Various Sorghum and Natural Gas Prices in the Texan Panhandle. ($ per acre)

P_{NG} ($/mcf)	Price of Sorghum ($/cwt)												
	2.50	**2.75**	**3.00**	**3.25**	**3.50**	**3.75**	**4.00**	**4.25**	**4.50**	**4.75**	**5.00**	**5.25**	**5.50**
4.00	-116.3	-99.0	-81.1	-62.9	-44.3	-25.5	-6.5	12.7	32.0	51.4	70.9	90.5	110.2
4.50	-122.2	-105.4	-88.0	-70.1	-51.9	-33.3	-14.6	4.4	23.5	42.8	62.1	81.6	101.1
5.00	-127.7	-111.4	-94.5	-77.0	-59.1	-40.9	-22.4	-3.6	15.3	34.3	53.5	72.9	92.3
5.50	-132.6	-117.0	-100.6	-83.5	-66.0	-48.1	-29.9	-11.4	7.3	26.2	45.2	64.4	83.6
6.00	-137.1	-122.1	-106.3	-89.7	-72.6	-55.0	-37.1	-18.9	-0.4	18.3	37.1	56.1	75.2
6.50	-141.2	-126.9	-111.6	-95.5	-78.8	-61.6	-44.0	-26.1	-7.9	10.6	29.2	48.0	67.0
7.00	-144.7	-131.2	-116.5	-100.9	-84.7	-67.9	-50.6	-33.0	-15.0	3.2	21.6	40.2	58.9
7.50	-147.8	-135.1	-121.0	-106.0	-90.2	-73.8	-56.9	-39.6	-22.0	-4.0	14.2	32.6	51.1
8.00	-150.5	-138.5	-125.2	-110.8	-95.5	-79.5	-63.0	-46.0	-28.6	-11.0	7.0	25.2	43.6
8.50	-152.6	-141.6	-128.9	-115.1	-100.4	-84.9	-68.7	-52.1	-35.1	-17.7	0.0	18.0	36.2
9.00	-154.3	-144.2	-132.3	-119.1	-104.9	-89.9	-74.2	-57.9	-41.2	-24.1	-6.7	11.0	29.0
9.50	-155.5	-146.3	-135.3	-122.8	-109.2	-94.6	-79.4	-63.5	-47.1	-30.3	-13.1	4.3	22.1
10.00	-156.3	-148.1	-137.9	-126.1	-113.0	-99.0	-84.2	-68.8	-52.7	-36.3	-19.4	-2.2	15.3
10.50	-156.6	-149.4	-140.1	-129.0	-116.6	-103.1	-88.8	-73.8	-58.1	-42.0	-25.4	-8.5	8.8
11.00	-156.6	-150.4	-141.9	-131.6	-119.8	-106.9	-93.1	-78.5	-63.2	-47.4	-31.2	-14.5	2.5
11.50	-156.6	-150.8	-143.3	-133.8	-122.7	-110.4	-97.1	-82.9	-68.1	-52.7	-36.7	-20.4	-3.6
12.00	-156.6	-150.9	-144.3	-135.7	-125.3	-113.6	-100.8	-87.1	-72.7	-57.6	-42.0	-26.0	-9.5
Dryland	-46.9	-41.4	-35.9	-30.4	-24.9	-19.4	-13.9	-8.3	-2.8	2.7	8.2	13.7	19.2

Table 3a. Optimum Level of Irrigation in Acre-Inches under Various Wheat and Natural Gas Prices in the Texas Panhandle*.

P_{NG} ($/mcf)	Price of Wheat ($/bu)												
	2.50	**2.75**	**3.00**	**3.25**	**3.50**	**3.75**	**4.00**	**4.25**	**4.50**	**4.75**	**5.00**	**5.25**	**5.50**
4.00	9.9	10.5	11.0	11.5	12.0	12.4	12.7	13.1	13.4	13.6	13.9	14.1	14.3
4.50	9.2	9.9	10.5	11.0	11.4	11.9	12.3	12.6	12.9	13.2	13.5	13.7	13.9
5.00	8.6	9.3	9.9	10.4	10.9	11.4	11.8	12.1	12.5	12.8	13.1	13.3	13.5
5.50	8.1	8.7	9.3	9.9	10.4	10.9	11.3	11.7	12.0	12.3	12.6	12.9	13.2
6.00	7.5	8.2	8.8	9.4	9.9	10.4	10.8	11.2	11.6	11.9	12.2	12.5	12.8
6.50	7.0	7.6	8.3	8.9	9.4	9.9	10.3	10.8	11.2	11.5	11.8	12.1	12.4
7.00	6.5	7.1	7.8	8.4	8.9	9.4	9.9	10.3	10.7	11.1	11.4	11.8	12.0
7.50	6.0	6.7	7.3	7.9	8.4	9.0	9.4	9.9	10.3	10.7	11.0	11.4	11.7
8.00	5.5	6.2	6.8	7.4	8.0	8.5	9.0	9.5	9.9	10.3	10.7	11.0	11.3
8.50	5.1	5.8	6.4	7.0	7.5	8.1	8.6	9.0	9.5	9.9	10.3	10.6	11.0
9.00	4.7	5.3	5.9	6.5	7.1	7.6	8.2	8.6	9.1	9.5	9.9	10.3	10.6
9.50	4.3	4.9	5.5	6.1	6.7	7.2	7.7	8.2	8.7	9.1	9.5	9.9	10.2
10.00	3.9	4.5	5.1	5.7	6.3	6.8	7.3	7.8	8.3	8.7	9.2	9.5	9.9
10.50	3.6	4.2	4.8	5.3	5.9	6.4	7.0	7.5	7.9	8.4	8.8	9.2	9.5
11.00	3.3	3.8	4.4	5.0	5.5	6.1	6.6	7.1	7.6	8.0	8.4	8.8	9.2
11.50	2.9	3.5	4.1	4.6	5.2	5.7	6.2	6.7	7.2	7.6	8.1	8.5	8.9
12.00	2.6	3.2	3.7	4.3	4.8	5.3	5.9	6.4	6.8	7.3	7.7	8.1	8.5

*** - Optimum level of available water adjusted for natural precipitation during the growing season and soil water extraction (10.64 ac. in.)**

Table 3b. Net Return to Land and Irrigation when Applying Irrigation to Maximize Profits under Various Wheat and Natural Gas Prices in the Texan Panhandle. ($ per acre)

P_{NG} ($/mcf)	Price of Wheat ($/bu)												
	2.50	**2.75**	**3.00**	**3.25**	**3.50**	**3.75**	**4.00**	**4.25**	**4.50**	**4.75**	**5.00**	**5.25**	**5.50**
4.00	-11.5	7.0	25.9	45.0	64.3	83.8	103.4	123.1	142.9	162.8	182.8	202.8	223.0
4.50	-16.4	1.9	20.4	39.3	58.3	77.6	97.0	116.5	136.2	156.0	175.8	195.8	215.8
5.00	-21.0	-3.0	15.3	33.8	52.6	71.7	90.9	110.3	129.8	149.4	169.1	188.9	208.8
5.50	-25.2	-7.6	10.4	28.7	47.2	66.0	85.0	104.2	123.5	143.0	162.6	182.2	202.0
6.00	-29.2	-11.9	5.8	23.8	42.1	60.6	79.4	98.4	117.5	136.8	156.2	175.8	195.4
6.50	-32.9	-15.9	1.4	19.1	37.2	55.5	74.0	92.8	111.7	130.8	150.1	169.5	189.0
7.00	-36.3	-19.7	-2.7	14.7	32.5	50.6	68.9	87.4	106.2	125.1	144.2	163.4	182.7
7.50	-39.5	-23.2	-6.5	10.6	28.1	45.9	63.9	82.3	100.8	119.5	138.4	157.5	176.7
8.00	-42.4	-26.5	-10.1	6.7	23.9	41.4	59.3	77.3	95.7	114.2	132.9	151.8	170.9
8.50	-45.1	-29.5	-13.4	3.1	20.0	37.2	54.8	72.6	90.7	109.1	127.6	146.3	165.2
9.00	-47.6	-32.3	-16.6	-0.4	16.2	33.2	50.5	68.1	86.0	104.1	122.5	141.0	159.7
9.50	-49.9	-34.9	-19.5	-3.6	12.7	29.4	46.5	63.8	81.5	99.4	117.5	135.9	154.4
10.00	-52.0	-37.4	-22.2	-6.6	9.4	25.8	42.6	59.7	77.2	94.8	112.8	130.9	149.3
10.50	-53.9	-39.6	-24.7	-9.4	6.3	22.5	39.0	55.9	73.0	90.5	108.2	126.2	144.3
11.00	-55.7	-41.6	-27.1	-12.0	3.4	19.3	35.5	52.2	69.1	86.3	103.8	121.6	139.6
11.50	-57.2	-43.5	-29.2	-14.5	0.7	16.3	32.3	48.6	65.3	82.3	99.6	117.2	135.0
12.00	-58.6	-45.2	-31.2	-16.7	-1.8	13.5	29.2	45.3	61.8	78.5	95.6	112.9	130.5
Dryland	-3.0	2.0	7.0	12.0	17.0	22.0	27.0	32.0	37.0	42.0	47.0	52.0	57.0

Table 4. Net Return, Water Use, and Production of Corn, Sorghum, and Wheat under Various Irrigation Strategies in the Texas Panhandle.*

	Crop/Production Method				
	Corn Sprinkler	Sorghum Sprinkler	Wheat Sprinkler	Sorghum Dryland	Wheat Dryland
Direct Expense	318.57	179.77	129.73	85.00	47.94
Fixed Expense	56.22	33.60	49.36	16.85	13.39
Total Direct and Fixed Expense	374.79	213.37	179.09	101.85	61.33
Commodity Prices	3.00	4.50	3.00	4.50	3.00
Natural Gas Price per Mcf	6.00	6.00	6.00		
Variable Irrigation Expense per ac.in.					
Natural Gas	6.11	6.11	6.11		
Repairs and Maintenance	2.03	2.03	2.03		
	8.14	8.14	8.14		
Irrigation Decision Criterian					
Max Yield					
AW (ac. in.)	38.79	34.04	29.58		
Yield (lbs.)	11,368.22	8,161.43	4,981.20	1,920.00	1,200.00
Irrigation (ac. In.)	28.95	23.03	18.94		
Irrigation Cost ($)	235.60	187.42	154.13		
Total Cost ($)	610.39	400.79	333.22	101.85	61.33
Total Revenue ($)	609.01	367.26	297.00	86.40	68.38
Net Return to Land and Irrigation ($)	(1.37)	(33.52)	(36.22)	(15.45)	7.05
Meet 100% PET Requirement					
AW (ac. in.)	35.80	27.02	22.36		
Yield (lbs.)	11,301.95	7,613.83	4,628.40	1,920.00	1,200.00
Irrigation (ac. In.)	25.96	16.01	11.72		
Irrigation Cost ($)	211.26	130.29	95.38		
Total Cost ($)	586.05	343.66	274.47	101.85	61.33
Total Revenue ($)	605.46	342.62	279.14	86.40	68.38
Net Return to Land and Irrigation ($)	19.41	(1.04)	4.68	(15.45)	7.05
Maximize Profits					
AW (ac. in.)	28.51	25.90	19.43		
Yield (lbs.)	10,587.35	7,424.63	4,281.55	1,920.00	1,200.00
Irrigation (ac. In.)	18.67	14.89	8.79		
Irrigation Cost ($)	151.97	121.17	71.53		
Total Cost ($)	526.76	334.54	250.62	101.85	61.33
Total Revenue ($)	567.18	334.11	261.55	86.40	68.38
Net Return to Land and Irrigation ($)	40.42	(0.44)	10.93	(15.45)	7.05

*** Yields, water availability and irrigation developed from Agripartners project, 1998-2003. Direct and fixed cost derived from Texas A&M University projected cost and return crop budgets for 2005.**

Table 5. New Return, Water Use, Cost and Revenue under Various Irrigation Criterian when Sufficient Water is Available to Maximize Corn Yield.

	Irrigation Decision Criterian / Crop		
	Prod. Max Corn	100% PET Corn	Profit Max Corn
Land (ac.)	1,000	1,000	1,000
Irrigation Water Available (ac. In.)	28,950	28,950	28,950
Irrigation Water Used (ac. In.)	28,950	25,960	18,674
Production (bus.)	203,004	201,821	189,060
Direct and Fixed Expense ($)	374,790	374,790	374,790
Irrigation Expense ($)	235,595	211,262	151,970
Total Cost ($)	610,385	586,052	526,760
Total Revenue ($)	609,012	605,462	567,179
Net Return to Land and Irrigation ($)	(1,373)	19,409	40,419

Table 6. Optimum Enterprise Combinations under Various Irrigation Criterion in Response to a 20 % reduction in Available Irrigation Water.

Irrigation Decision Criterion	Crop / Irrigation		Total
	Corn Irrigated	Wheat Nonirrigated	
Maximize Yield per Acre (water reduced 20%)			
Land (ac.)	800	200	1,000
Irrigation Water Available (ac. In.)	23,160		
Irrigation Water Used (ac. In.)	23,160		23,160
Production (bus.)	162,403	4,000	
Direct and Fixed Expense ($)	299,832	12,266	312,098
Irrigation Expense ($)	188,476		188,476
Total Cost ($)	488,308	12,266	500,574
Total Revenue ($)	487,209	13,675	500,884
Net Return to Land and Irrigation ($)	(1,099)	1,409	310
Meet 100% PET (water reduced 20%)			
	Corn Irrigated	Wheat Nonirrigated	Total
Land (ac.)	892	108	1,000
Irrigation Water Available (ac. In.)	23,160		
Irrigation Water Used (ac. In.)	23,160		23,160
Production (bus.)	180,053	2,157	
Directand Fixed Expense ($)	334,366		334,366
Irrigation Expense ($)	188,476		188,476
Total Cost ($)	522,842	6,615	529,457
Total Revenue ($)	540,158	7,375	547,533
Net Return to Land and Irrigation ($)	17,316	760	18,076

Table 6. continued

Profit Maximization (water reduced 20%)	Corn Irrigated	Total
Land (ac.)	1,000	1,000
Irrigation Water Available (ac. In.)	23,160	
Irrigation Water Used (ac. In.)	18,674	18,674
Production (bus.)	189,060	
Directand Fixed Expense ($)	374,790	374,790
Irrigation Expense ($)	151,970	151,970
Total Cost ($)	526,760	526,760
Total Revenue ($)	567,179	567,179
Net Return to Land and Irrigation ($)	40,419	40,419

Table 7. Optimum Enterprise Combinations under Various Irrigation Criterian in Response to a 40 % reduction in Available Irrigation Water.

Irrigation Decision Criterion	Crop / Irrigation		Total
	Corn Irrigated	Wheat Nonirrigated	
Maximize Yield per Acre (water reduced 40%)			
Land (ac.)	600	400	1,000
Irrigation Water Available (ac. In.)	17,370		
Irrigation Water Used (ac. In.)	17,370		17,370
Production (bus.)	121,802	480,000	
Directand Fixed Expense ($)	224,874	24,532	249,406
Irrigation Expense ($)	141,357		141,357
Total Cost ($)	366,231	24,532	390,763
Total Revenue ($)	365,407	27,350	392,757
Net Return to Land and Irrigation ($)	(824)	2,818	1,994

Meet 100% PET (water reduced 40%)	Corn Irrigated	Wheat Nonirrigated	Total
Land (ac.)	669	331	1,000
Irrigation Water Available (ac. In.)	17,370		
Irrigation Water Used (ac. In.)	17,370		17,370
Production (bus.)	135,039	397,072	
Directand Fixed Expense ($)	250,774	20,294	271,068
Irrigation Expense ($)	141,357		141,357
Total Cost ($)	392,131	20,294	412,425
Total Revenue ($)	405,118	22,625	427,743
Net Return to Land and Irrigation ($)	12,987	2,331	15,318

Table 7. continued

Profit Maximization (water reduced 40%)	Corn Irrigated	Wheat Nonirrigated	Total
Land (ac.)	930	70	1,000
Irrigation Water Available (ac. In.)	17,370		
Irrigation Water Used (ac. In.)	17,370		17,370
Production (bus.)	175,857	83,803	
Directand Fixed Expense ($)	348,616	4,283	352,899
Irrigation Expense ($)	141,357		141,357
Total Cost ($)	489,973	4,283	494,256
Total Revenue ($)	527,570	4,775	532,345
Net Return to Land and Irrigation ($)	37,597	492	38,089

Profit Maximization (water reduced 40%)**	Corn Irrigated	Wheat Irrigated	Total
Land (ac.)	930	70	1,000
Irrigation Water Available (ac. In.)	17,370		
Irrigation Water Used (ac. In.)**	17,370	614	17,984
Production (bus.)	175,857	4,983	
Directand Fixed Expense ($)	348,616	12,507	361,123
Irrigation Expense ($)	141,357	4,995	146,352
Total Cost ($)	489,973	17,502	507,476
Total Revenue ($)	527,570	18,265	545,835
Net Return to Land and Irrigation ($)	37,597	763	38,360

**** Additional pumping capacity due to winter cropping season.**

References

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.

Amosson, S.H., L. New, L. Almas, F. Bretz, and T Marek. *Economics of Irrigation Systems."* Texas Agricultural Extension Bulletin B-6113, Texas Cooperative Extension, The Texas A&M University System, 2001.

Amoson, S., J. Smith, L. Almas, F. Bretz, and M. Freeman. *Texas Crop and Livestock Enterprise Budgets, Texas High Plains, Projected for 2005.* Texas Cooperative Extension, The Texas A&M University System, 2004.

Heady, E.O. and J.L. Dillon. *Agricultural Production Functions,* Iowa State University Press, Ames. 1961.

New, L. *AgriPartners Irrigation Result Demonstrations.* Texas Agricultural Extension Service, Texas A&M University System, (Issues 1998, 1999 2000, 2001, 2002, and 2003).