Water use efficiency and maximizing profitability of grain sorghum production in the Texas Panhandle

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Abstract:

The reduction in the availability of irrigation water and the increase in pumping costs resulting from the decline in the Ogallala Aquifer make good management decisions more critical for the survival of the farm firm and the success of the agricultural sector in the Texas Panhandle. Response functions for irrigation and percentage potential evapotranspiration (PET) in the production of grain sorghum are estimated. The response functions are transferred into value product functions and combined with an irrigation energy cost function to determine the profit maximizing irrigation strategy. Three management decision variables; total water available, the level of irrigation and the water to meet crop ET requirements are evaluated. Grain sorghum yield, natural precipitation, irrigation, soil moisture content, potential evapotranspiration, and percent potential evapotranspiration (PET) data, collected over the period from 1998 through 2007 by commercial producers participating in the AgriPartners program are used to estimate the response functions. Results indicate that the optimum level of irrigation increases as the price of sorghum increases and decreases as the price of natural gas increases.

Key words: Grain sorghum, ET, maximizing profit, irrigation efficiency, input use optimization, water conservation, Ogallala Aquifer, Texas Panhandle.

JEL Classification: Q12, Q15, Q25, Q32, and Q34

Introduction:

Irrigation is essential to maintaining agricultural productivity which is the main contributor to the regional economy. The development of irrigation in the region is a recent phenomenon with virtually all of the development occurring 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 significance of irrigation to agricultural production is shown by the differential between the yield of irrigated and non-irrigated corn. In 2009, the yield on the 846,000 acres of irrigated corn averaged 212 bushels per acre, compared to an average of 57 bushels per acre on the 5,000 acres of non-irrigated corn (Texas Agricultural Statistics Service 2010). 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%.

Precipitation is not only limiting but is also highly variable. At the Bushland agricultural research center near Amarillo the annual average precipitation over the 130-year period from 1880 through 2010 is 20.53 inches. However, the range in annual precipitation is from less than 9 inches to over 40 inches. In addition to the pronounced year-to-year variations with as much as 15 to 20 inch differences in consecutive years there also are major wet and dry cycles observed. Short periods of significantly above average precipitation are usually followed by long periods of below average-to-average precipitation. Over 50% of the annual precipitation is received during the summer growing season from May through October. The months with the highest average rainfall are May, June and August.

Grain sorghum is an important feed grain crop in the Texas Panhandle due to its drought resistance and ability to produce under limited precipitation. Although important since the establishment of farming in the Panhandle, sorghum production didn’t expand rapidly until the 1950s as a result of hybrid grain sorghum, irrigation and nitrogen fertilizer. Production peaked in the 1960s but after decreasing significantly appears to have stabilized in recent years. Dryland production of grain sorghum is becoming more important as the water level in the Ogallala declines and irrigation is reduced. Previous analyses of the profitability of irrigated and non-irrigated sorghum production have been based on simple budgets reflecting current or recommend practices (Bean 2000; Johnson and Falconer 2001; and Amosson et al 2003).

The economic focus on irrigation from the Ogallala aquifer and the impact on the region has shifted from development and expansion in the 1950s and 1960s to the implications of the depletion of the aquifer in the 1990s and 2000s (Grubb 1966; Osborn and McCrary 1972; Musick et al 1990; Amosson et al 2011; Colette, Robinson, and Almas 2001). The decline in the water level in the Ogalalla aquifer is an on-going concern. Wells that produced 1000 to 1200 gallons per minute in the 1960's often produced less than 200 gallons per minute in the 1990's. Since there is only limited recharge of the Ogalalla aquifer in this area, irrigation water is a fixed supply and excessive pumping results in shortening the economic life of the farming operation and in reducing the returns to the resources held by the farmer (Amosson et al. 2011).

Texas agriculture generated over $16.5 billion in receipts in 2009. Although the High Plains represents less than 15% of the area it accounts for over 40% of the value of agricultural production for the state. In addition to leading the state in the production of feed grain, wheat, and cotton; more than 6 million cattle are fed annually within 75 miles of Amarillo (Texas Agricultural Statistics Service 2010).

Irrigation is important to maintaining the agricultural productivity and the regional economy. The Texas Panhandle is a region of Texas with twenty six counties. It depends on the Ogallala Aquifer for irrigated agricultural production. The regional water plan by the Panhandle Water Planning Group (Region A) estimates that irrigated agriculture uses more than ninety percent of all water consumed in the region. Agriculture is the largest industries in the Texas High Plains region. Although the study area represents only 15% of the agricultural land in the state, 56.9% of the irrigated sorghum in the state is produced in District 1-N.

Most of that water comes from Ogallala Aquifer ground water source. The Ogallala Aquifer is declining at an excessive rate to irrigate crops such as corn, cotton, grain sorghum and wheat in the area. These crops require large quantities of water especially during times of drought. With declining Ogallala Aquifer the pumping cost has increased due to increase in pumping lift and higher energy costs. The objectives of this study are to:

1) Estimate marginal value product of irrigation water applied to sorghum in the Texas Panhandle,
2) Estimate the profit maximizing level of irrigation for sorghum at various combinations of sorghum market price and the natural gas price, and
3) Perform comparative analysis of water use between corn and grain sorghum and estimate potential water saving.

Background:

The water response function for sorghum 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. Jensen and Musick (1960) were among the first to recognize the relationship between evapotranspiration (ET) and sorghum grain production. 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^oF), 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.

There have been many studies which investigated the relation of water depletion in Texas High Plains and the practice of agriculture. Texas is one of the top water consuming states in the United States and is increasingly relying on groundwater resources. Groundwater uses are attracting more attention as a mechanism to satisfy both social needs of water and irrigation for agriculture. However, excessive extraction is being used exacerbated by the rule of capture that governs the use of groundwater in Texas combined with widespread subdivision of land for agriculture. The growth of water demand because of population increase and expansion of agriculture will be a challenge for water planners. One option to maintain sorghum production requirement with the decline of water resources is to replace corn with more water use efficient crops. Because sorghum has shown more prospect futures to respond forage requirement, it will be the focal crop studied in this research. Many scientific arguments are supported this point of view as sorghum is more suited to semi-arid conditions than corn for several reasons including lower transpirations ratios, slower leaf and stalk wilting, recovering after drought (Martin, 1930), and lower irrigation requirement. Additionally sorghum may deplete less water from the soil than corn and sorghum silage has been shown to have 27% lower evapotranspiration (ET) than corn (Howell et al., 2008).

Preliminary result from research conducted in Texas, USA indicate that sorghum maintain lower ET rates throughout the growing season and use less cumulative water (Howell et al., 2008). Even at similar ET rates, corn tends to use more water than sorghum in the Southern High Plains because of early planting dates and longer growing season (Howell et al., 1997). If sorghum grain production can be maintained at acceptable level, while conserving water and reducing cost associated with irrigation, producers may be willing to utilize as alternative crop. According to Colette and Almas, 2008, the declining availability of irrigation water from Ogallala Aquifer combined with increasing energy cost make irrigation strategies much more critical in Texas High Plains.

Data and Methods:

Data included in this study represents production information collected from producers cooperating in the AgriPartners Demonstration 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 (New 1999-2007).

Data for estimating the water response function for sorghum includes observations complied from several experiments conducted over a six-year period at the Bushland Agriculture Research Station West of Amarillo, TX. The water use and corresponding yields are measured using a weighing lysimeter. Linear, quadratic, square root, natural log, and Cobb-Douglas type functional forms are estimated using the SAS procedure PROC GLM. Dummy variables will account for the exogenous variables associated with the different experiments. Data for relating to the application of irrigation water at the producer level is based on records provided by the Agri Partners Irrigation Demonstration Project. Cooperators provided observations of irrigation water application and resulting sorghum yield representing thirteen counties over a ten year period, 1998 through 2007.

Production costs: The cost of production is the sum of the fixed cost and the variable input cost incurred in the production process. In evaluating the optimum level of a single variable input, the levels of all of the other inputs are assumed constant. The costs associated with all other inputs are considered as a part of fixed cost and only the cost of the single variable input is included in variable cost. The fixed cost is a constant and independent of the amount of water applied. The variable input cost is directly associated with the level of variable input. 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.

The impact of a change in the price of fuel is observed in the change in the cost of fuel. Since natural gas is the predominate source of energy for pumping irrigation water in the area, natural gas is used in the calculations. 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}) (Equation 2).

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

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 3).

$$NG = 0.0038*L+ 0.088*PSI - ((7.623E\text{-}6)* PSI)*(L) - (3.3E\text{-}6)*L^2 \qquad (3)$$

Where NG is the mcf of natural gas, L is the system lift in feet, and PSI is the system pressure per square inch. NG, LMR, LC and AIC are known constants for an irrigation system. 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.

$$TC = FC +(1.018P_{NG} + 8.75)\ AW \qquad (4)$$

The Marginal Factor Cost of water (MFC_{AW}) can now be calculated from the cost function. The MFC_{AW} is the first derivative of the cost function with respect to the input, water (AW) (Equation 5)

$$MFC_{AW} \quad = \quad 1.018\ P_{NG} + 8.75 \qquad (5)$$

Results and Discussion:

Three approaches to the estimation of the sorghum-water response function are evaluated. The first approach is the traditional approach in which grain production is defined as a function of the total water available during the growing season. The second approach is to define the production function of sorghum grain production as a function of the irrigation water added to the natural precipitation available during the growing season. The third approach is to determine the application of an input based on the physiological requirement of the crop.

Estimation of response function and economic optimum level of irrigation: Three approaches to the estimation of the sorghum-water response function are evaluated. The first approach is the traditional approach in which grain 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 sorghum yield and water available. The estimated coefficients for the terms representing water application are shown in Equation 6.

$$Ys = 0.3506 + 4.1530\ AW - 0.0443\ AW^2 \qquad (6)$$

The Marginal Physical Product of Water in Area A (MPP_{WA}) is equal to the derivative of the response function with respect to the input water (Equation 7).

$$MPP_{AW} = 4.1530 - 0.0886\ AW \qquad (7)$$

The Marginal Value Product of water (MVP_{WA}) is obtained by multiplying the Marginal Physical Product of water (MPP_{AW}) by the price of the product (P_Y) (Equation 8).

$$MVP_{AW} = (4.1530 - 0.0886\ AW)\ P_y \qquad (8)$$

The optimal economic level of a productive input is based on the principle of profit maximization (Heady and Candler 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. The MVP is equal to the increase in output obtained from the use of an additional unit of input, Marginal Physical Product (MPP), multiplied by the price of the output (P_Y). The Optimum level of the input water application is determined by equating the Marginal Value Product of water (MVP_{WA}) from Equation 8 and the Marginal Factor Cost of water (MFC_W) from Equation 5.

$$MVP_{AW} = MFC_W \tag{9}$$

$$(4.1530 - 0.0886\ AW)\ P_Y = 1.018 P_{NG} + 8.75$$

Solving for the level of water availability (AW) produces a function in the price of natural gas (P_{NG}) and the price of the output (P_Y) (Equation 10).

$$AW = [4.1530 - \{(1.018\ PNG + 8.75)/Py\}/0.0886] \tag{10}$$

Profit maximizing levels of water availability derived from Equation 10 for sorghum prices between \$4.50 and \$8 and natural gas prices between \$7 and \$14 are presented Table 1.

Optimization of irrigation supplementing natural precipitation: The second approach is to define the production function of sorghum grain production 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 sorghum 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 estimated coefficients for the terms representing water application are shown in Equation 11.

$$Y_s = 24.2415 + 4.7565IW - 0.1329IW^2 + 1.5983RW \tag{11}$$

where Y_s is the production of sorghum in hundred weight (cwt) per acre, RW is the natural precipitation in inches; and IW is acre-inches of supplemental irrigation.

The Marginal Physical Product of Irrigation Water (MPP_{IW}) is equal to the derivative of the response function with respect to the input water (Equation 12).

$$MPP_{IW} = 4.7565 - 0.2658IW \qquad (12)$$

The Marginal Value Product of water (MVP_{IW}) is obtained by multiplying the Marginal Physical Product of irrigation water (MPP_{IW}) by the price of the product (P_Y) (Equation 13).

$$MVP_{IW} = (4.7565 - 0.2658IW)\ P_y \qquad (13)$$

The Optimum level of the input water application is determined by equating the Marginal Value Product of water (MVP_{IW}) from Equation 13 and the Marginal Factor Cost of water (MFC_W) from Equation 5. Solving for the level of irrigation water (IW) produces a function in the price of natural gas (P_{NG}) and the price of the output (P_Y) (Equations 14 and 15).

$$(4.7565 - 0.2658IW)\ P_y = 1.018P_{NG} + 8.75 \qquad (14)$$

$$IW = [4.7565 - \{(1.018\ PNG + 8.75)/Py\}/0.2658] \qquad (15)$$

Optimal irrigation water to be applied at natural gas prices between \$7 and \$14 per mcf and sorghum prices between \$4.5 and \$8 per cwt are shown in Table 2.

Optimization based on Potential Evapotranspiration: The third approach is to determine the application of an input based on the physiological requirement of the crop as determined by Potential Evapotranspiration (PET). In the third method the production of sorghum grain 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 PET. The quadratic form produces the best explanation of the relationship between sorghum yield and water available to meet ET requirements. The estimated coefficients for the terms representing water application are shown in Equation 16.

$$Ys = -6.7929 + 1.2783PET - 0.0041PET^2 \qquad (16)$$

Since PET is a measurement instead of an input, the productivity of the PET must reflect the relationship between PET and water availability. The estimate is a linear model PET = 12.1961 + 3.1914AW. The change in PET with respect to AW is equal to 3.1914. 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 marginal physical product of water applied to meet evapotranspiration requirements as reflected by the PET is shown in Equation 17. The marginal value product is shown in Equation 18.

$$MPP_{PET} = (1.2783 - 0.0082*(12.1961 + 3.1914AW))*(3.1914)$$

$$MPP_{PET} = 3.7604 - 0.0832AW \qquad (17)$$

$$MVP_{PET} = (3.7604 - 0.0832AW)\ Py \qquad (18)$$

The Optimum level of the input water application is determined by equating the Marginal Value Product of water (MVP_{PET}) from Equation 18 and the Marginal Factor Cost of water (MFC_W) from Equation 5. Solving for the level of available water (AW) produces a function in the price of natural gas (P_{NG}) and the price of the output (P_Y) (Equations 19 and 20).

$$(3.7604 - 0.0832AW)\ Py = 1.018P_{NG} + 8.75 \qquad (19)$$

$$AW_{PET} = [3.7604 - \{(1.018\ PNG + 8.75)/Py\}/0.0832] \qquad (20)$$

Optimal irrigation water to be applied at natural gas prices between \$7 and \$14 per mcf and sorghum prices between \$4.5 and \$8 per cwt are shown in Table 3.

Water Conservation Potential by Changing Crop Type:

One method of reducing groundwater use is changing the crop type that is planted. The assumption is that corn acres will be converted to sorghum. Current corn acres if shifted to sorghum acres at the rate of 15 percent by 2020 and 30 percent by 2030 could result in significant water conservation and reduction in irrigation water demand (Tewari et al., 2010). Two methodologies for calculating water saving in acre – feet are examined for two cropping alternatives. One approach utilizes the difference in PET irrigation water use estimates by crop and county that incorporates the application efficiency rating. The water use estimates are presented in Table 4. The second approach uses a flat rate of water savings of 5 acre – inches per year when changing from irrigated corn to irrigated sorghum. When shifting irrigated corn acres to sorghum, there is water saving potential of 7.56 million acre feet over a period of 50 years.

Summary: Often the answers to management decision problems cannot be found in individual controlled experiments but must be developed under commercial management conditions. Collecting adequate observations to estimate management decision functions for commercial producers is often difficult. Fortunately the participation of progressive producers in the Texas Panhandle in the AgriPartners Irrigation Demonstration Project allows access to the information needed to estimate a response function relating sorghum yield as a function of water availability and irrigation.

Although production cost will vary for different types of delivery systems and with different water lifts, for a given delivery system, such as LESA and a known lift the cost function can be expressed in terms of the energy cost. The response and cost functions are used to determine the profit maximizing level of water availability for various price levels for sorghum and natural gas.

Three approaches to making the management decision on the amount of water to apply to maximize profits and returns to resources from grain sorghum 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 indication the total water needs but only indirectly addressing the management decision of irrigation levels.

In the second approach, irrigation is viewed as a supplementation to natural precipitation. Irrigation becomes a management decision variable. The response function indicates that grain 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.

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 that total water requirement based on percent evapotranspiration levels are lower than the optimal total water requirements that would provide a water stress free environment for the crop.

The analysis for natural gas prices between \$7 and \$14 per mcf and sorghum prices between \$4.50 and \$8 per cwt indicate that the amount of water to apply increases as the price of sorghum increases. Conversely, for a fixed price of sorghum the optimal water application rate declines as the price of natural gas increases.

Table 1: Optimum water availability for meeting crop requirements under different sorghum and natural gas prices

Price of Sorghum ($/cwt)

PNG	**4.50**	**5.00**	**5.50**	**6.00**	**6.50**	**7.00**	**7.50**	**8.00**
7.00	7.05	11.04	14.29	17.01	19.31	21.28	22.98	24.48
7.50	5.78	9.89	13.25	16.05	18.42	20.45	22.22	23.76
8.00	4.50	8.74	12.21	15.09	17.54	19.63	21.45	23.04
8.50	3.22	7.59	11.16	14.14	16.65	18.81	20.68	22.32
9.00	1.95	6.44	10.12	13.18	15.77	17.99	19.92	21.60
9.50	0.67	5.29	9.07	12.22	14.89	17.17	19.15	20.88
10.00	-0.61	4.14	8.03	11.26	14.00	16.35	18.39	20.17
10.50	-1.88	2.99	6.98	10.31	13.12	15.53	17.62	19.45
11.00	-3.16	1.84	5.94	9.35	12.24	14.71	16.85	18.73
11.50	-4.44	0.70	4.89	8.39	11.35	13.89	16.09	18.01
12.00	-5.71	-0.45	3.85	7.43	10.47	13.07	15.32	17.29
12.50	-6.99	-1.60	2.80	6.48	9.58	12.25	14.56	16.58
13.00	-8.27	-2.75	1.76	5.52	8.70	11.43	13.79	15.86
13.50	-9.54	-3.90	0.72	4.56	7.82	10.61	13.02	15.14
14.00	-10.82	-5.05	-0.33	3.60	6.93	9.79	12.26	14.42

Table 2: Optimum irrigation application in acre-inches for meeting crop requirement under different sorghum and natural gas prices

Price of Sorghum ($/cwt)

PNG	**4.50**	**5.00**	**5.50**	**6.00**	**6.50**	**7.00**	**7.50**	**8.00**
7.00	4.62	5.95	7.03	7.94	8.71	9.36	9.93	10.43
7.50	4.20	5.57	6.69	7.62	8.41	9.09	9.68	10.19
8.00	3.77	5.18	6.34	7.30	8.12	8.81	9.42	9.95
8.50	3.35	4.80	5.99	6.98	7.82	8.54	9.16	9.71
9.00	2.92	4.42	5.64	6.66	7.53	8.27	8.91	9.47
9.50	2.49	4.03	5.29	6.34	7.23	7.99	8.65	9.23
10.00	2.07	3.65	4.95	6.02	6.94	7.72	8.40	8.99
10.50	1.64	3.27	4.60	5.71	6.64	7.45	8.14	8.75
11.00	1.22	2.89	4.25	5.39	6.35	7.17	7.89	8.51
11.50	0.79	2.50	3.90	5.07	6.05	6.90	7.63	8.27
12.00	0.37	2.12	3.55	4.75	5.76	6.63	7.38	8.03
12.50	-0.06	1.74	3.21	4.43	5.47	6.35	7.12	7.80
13.00	-0.48	1.35	2.86	4.11	5.17	6.08	6.87	7.56
13.50	-0.91	0.97	2.51	3.79	4.88	5.81	6.61	7.32
14.00	-1.34	0.59	2.16	3.47	4.58	5.53	6.36	7.08

Table 3: Sorghum optimum level of available water in acre-inches to meet the PET requirement

Price of Sorghum ($/cwt)

P_{NG}	**4.50**	**5.00**	**5.50**	**6.00**	**6.50**	**7.00**	**7.50**	**8.00**
7.00	2.79	7.03	10.50	13.39	15.84	17.94	19.75	21.34
7.50	1.43	5.81	9.39	12.37	14.90	17.06	18.94	20.58
8.00	0.07	4.59	8.28	11.35	13.96	16.19	18.12	19.82
8.50	-1.29	3.36	7.17	10.34	13.02	15.32	17.31	19.05
9.00	-2.64	2.14	6.05	9.32	12.08	14.44	16.49	18.29
9.50	-4.00	0.92	4.94	8.30	11.13	13.57	15.68	17.52
10.00	-5.36	-0.31	3.83	7.28	10.19	12.69	14.86	16.76
10.50	-6.72	-1.53	2.72	6.26	9.25	11.82	14.04	15.99
11.00	-8.08	-2.75	1.60	5.24	8.31	10.95	13.23	15.23
11.50	-9.44	-3.98	0.49	4.22	7.37	10.07	12.41	14.46
12.00	-10.80	-5.20	-0.62	3.20	6.43	9.20	11.60	13.70
12.50	-12.16	-6.43	-1.73	2.18	5.49	8.32	10.78	12.93
13.00	-13.52	-7.65	-2.84	1.16	4.55	7.45	9.97	12.17
13.50	-14.88	-8.87	-3.96	0.14	3.61	6.58	9.15	11.40
14.00	-16.24	-10.10	-5.07	-0.88	2.66	5.70	8.33	10.64

Table 4: Estimated water savings in acre-feet by county when converting from irrigated corn to irrigated sorghum using the PET irrigation water requirement

County	**Irrigated Corn Acres**	**Annual water savings for selected years**					**Total For 50 years**
		2020	**2030**	**2040**	**2050**	**2060**	
Armstrong	1,000	1,219	2,438	2,438	2,438	2,438	10,969
Carson	19,400	22,480	44,960	44,960	44,960	44,960	202,318
Dallam	126,800	144,552	289,104	289,104	289,104	289,104	1,300,968
Donley	1,500	1,899	3,799	3,799	3,799	3,799	17,094
Gray	6,800	7,650	15,300	15,300	15,300	15,300	68,850
Hansford	49,300	48,129	96,258	96,258	96,258	96,258	433,162
Hartley	120,200	143,038	286,076	286,076	286,076	286,076	1,287,342
Hutchinson	15,400	22,388	44,776	44,776	44,776	44,776	201,490
Lipscomb	3,400	4,144	8,288	8,288	8,288	8,288	37,294
Moore	60,000	70,800	141,600	141,600	141,600	141,600	637,200
Ochiltree	21,800	27,305	54,609	54,609	54,609	54,609	245,741
Randall	2,500	3,303	6,606	6,606	6,606	6,606	29,728
Roberts	1,700	1,781	3,562	3,562	3,562	3,562	16,027
Sherman	84,300	104,216	208,432	208,432	208,432	208,432	937,943
Bailey	11,900	8,271	16,541	16,541	16,541	16,541	74,435
Castro	119,700	83,192	166,383	166,383	166,383	166,383	748,724
Crosby	2,500	1,738	3,475	3,475	3,475	3,475	15,638
Floyd	13,600	9,452	18,904	18,904	18,904	18,904	85,068
Hale	46,500	32,318	64,635	64,635	64,635	64,635	290,858
Lamb	61,900	43,021	86,041	86,041	86,041	86,041	387,185
Parmer	63,800	44,341	88,682	88,682	88,682	88,682	399,069
Swisher	20,700	14,387	28,773	28,773	28,773	28,773	129,479
						Grand Total	**7,556,578**

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