Rainfall Variations and Risk Analysis of Dryland and Irrigated Agriculture in the Texas High Plains

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Abstract: The primary goal of the study was to assess the effect of rainfall variability on yield and income from crops. Ten percent decline in CV for precipitation favored dryland sorghum yield increase by 514 lbs/ac. In Deaf Smith County, 570,813 ac-ft. of irrigation water will be needed for irrigated sorghum if there is a 25% decrease in the average precipitation received for the next 50 years. Hansford County seasonal precipitation by ±2.69 inches will change the optimal profit by ±$27.26/ac. More irrigation water will be needed in the future if any less amount of precipitation is received.

Rainfall Variations and Risk Analysis of Dryland and Irrigated Agriculture in the Texas High Plains

Abstract

Agriculture production in the Texas High Plains is highly dependent on climate especially with the decline in water levels in the Ogallala Aquifer. There is increasing pressure on the Ogallala Aquifer as a result of an increase in population and expansion of agricultural production. The decline in water levels in the Ogallala Aquifer along with precipitation variability are affecting agricultural production, thus increasing the risk faced by farmers.

The primary goal of the study is to determine the effect of rainfall variability on yield and income from crops grown in the Texas High Pains. The specific objectives are to estimate the effect of precipitation variability on dryland and irrigated crops; to conduct risk analysis for dryland and irrigated crops and estimate revenue loss/gain due to variability in precipitation; and, to perform sensitivity analysis to analyze the effect of precipitation changes on profitability for a farm enterprise.

The information about the dryland county-level yield data was collected from the National Agricultural Statistics Service (NASS) for the period of 1972 to 2012 for dryland cotton and dryland sorghum while dryland wheat data was for the period of 1973 to 2012. The county-level climatic information was collected from the National Oceanic and Atmospheric Administration (NOAA). The information about irrigated corn was collected from AgriPartners Program from 1998 to 2007. The relationship between growing season precipitation variability and dryland yield was examined for dryland sorghum, dryland wheat, and dryland cotton using ordinary least square regression. The effect of precipitation fluctuation on irrigated corn

profitability, and irrigation water demand was also estimated. The coefficients of variation for price, yield, precipitation, and revenue were considered for different sub periods.

The average season county precipitation levels are 13.65 inches, 13.16 inches, and 15.01 inches for dryland sorghum (Deaf Smith County), dryland wheat (Hansford County), and dryland cotton (Lynn County) respectively. The R^2 values from the restricted models are 90%, 93% and 87% for dryland sorghum, dryland wheat, and dryland cotton respectively. The R^2 value of the restricted irrigated corn model was 96%. The higher the coefficient of variation for precipitation, the greater the risk faced by farmers. A decline in the coefficient of variation for precipitation by 9.59% favored dryland sorghum yield increase by 5.14 cwt/ac from 1972-1981 to 1982-1991.

In Deaf Smith County, 570,813 ac-ft. of irrigation water will be needed for irrigated sorghum if there is a 25% decrease in the average seasonal precipitation received for the next 50 years. At a natural gas price of $4.5/Mcf and corn sales price of $7/bu, variation in the Hansford County seasonal precipitation by ±2.69 inches will change the optimal profit by ±$27.26/ac. More irrigation water will be needed in the future if any less amount of precipitation is received.

Introduction

Agriculture production in the Texas High Plains is increasingly at the mercy of the climate especially with declining water levels in the Ogallala Aquifer. Agricultural production in the Texas High Plains faces production risk due to the uncertainty of and variability in climatic factors. Agriculture is extremely vulnerable to climate variability. Adams et al. (1998) explained that climate change is expected to influence crop and livestock production, water balances, input supply, and other components of agricultural systems. Climate factors like precipitation influence the availability of irrigation water because irrigation depends on precipitation for recharge (Kumar and Seethapathi, 2002).

Agricultural production is not totally dependent on rainfall in the Texas Panhandle, yet irrigation is still affected by climate variables. The use of the Ogallala Aquifer at a rate higher than the rate of recharge has led to dwindling water levels at various farms in the Texas High Plains. The decrease in available water from the Ogallala Aquifer has changed different farm management practices through the adoption of new and efficient irrigation technologies, planting of different crop mixes, and irrigated acreage being converted to dryland.

Most of the annual rainfall in Texas occurs in the form of rainstorms, when a large amount of precipitation falls over a short period of time. Precipitation is not only limiting, but is also highly variable. In Deaf Smith County, the annual average precipitation recorded over the last 64-year period from 1950 through 2013 was 17.73 inches. However, annual precipitation ranges from 7.72 inches to 36.64 inches. In addition to the pronounced year-to-year variation with as much as 10 to 13 inches difference in consecutive years, major wet and dry cycles were also observed. Shorter periods of significantly above average precipitation are usually followed by long periods of below average precipitation. Over 50% of the annual precipitation is received during the summer growing season from May through October.

Farmers or ranchers face different types of risks ranging from production risk to price risk. The variation in yield from agricultural production can occur as a result of extreme or below average weather conditions. Due to variation in precipitation from one year to the next, the cost incurred on irrigated farming varies as the cost of irrigation changes with the amount of supplementary water applied. Even at the same yield level, farm income varies based on the commodity price received.

Fannin (2011) summarized the effect of the 2011 drought on the Texas economy. The 2011 drought led to $5.2 billion in agricultural losses, making it the costliest on record. Direct damages by commodity include $2.06 billion for livestock, $750 million for hay, $1.8 billion for cotton, $327 million for corn, $243 million for wheat, and $63 million for sorghum while the indirect impact of the drought was $3.5 billion (Combs, 2012).

Research Objectives

The primary objective is to study the effect of rainfall variability on yield and income from crops grown in the Texas High Plains. The specific objectives are to: 1) Estimate the effect of precipitation variability on dryland and irrigated crops; 2) Conduct risk analysis for dryland and irrigated crops, and estimate revenue loss/gain due to variability in precipitation; and 3) Perform sensitivity analysis to analyze the effect of precipitation changes on profitability for a farm enterprise.

Climate Change and Agriculture

Many studies have been done to estimate the effect of climate on agriculture. Climatic factors influence agricultural productivity. McCarl et al. (1993) categorized some of the forces that influence agricultural production. Precipitation alters the water directly available to crops and the supplementary irrigation water supplies. Change in precipitation patterns increases the likelihood of short-run crop failures and long-run production declines (Nelson et al., 2009). The plants need adequate water to maintain temperature within their optimal range (Deschenes and Greenstone 2007). Changes in atmospheric carbon dioxide (CO_2) influence the growth of plants by altering the basic fuel for photosynthesis and water needed by plants as they grow along with weeds (McCarl et al., 1993). The dryland yield variation is driven by both precipitation and temperature changes. In addition to precipitation variability, climate variability may induce a higher temperature that increases the water requirements of crops (Nelson et al., 2009).

Yield Water Response

Lobell and Burke (2010) divided all the approaches used in estimating the effect of climate variability on yield into two categories. The process based model involved the use of experimental trials while the second approach involves the use of statistical model. The second approach uses historical data on crop yield and weather to estimate a simple regression equation which requires less calibration from the field. Kaufmann and Snell (1997) used hybrid regression to explain the link between climatic conditions and economic behavior. The model integrated the ability of a crop model to simulate the physical determinant of yield and the ability of a regression model to simulate the social determinant of yield. The result showed that 86% of the variation in corn yield was caused by the economic, climatic, and technical variables. Regression coefficients of the climate and economic variables were consistent with crop physiology and economic theory.

Tenure et al. (2008) studied the relationship between weather and technology on corn and soybean in the U.S Corn Belt. Weather information was used to show the effect of precipitation and temperature on the variation in yield. The study modified Thompson's model that used preseason precipitation, growing season precipitation, temperature, and time trend (technology) to explain variation yield. The research found strong evidence to show that the weather variables and a linear trend (technology) accounted for most of the variation in soybean yield while the estimated model explained at least 94% of the variation in corn.

Major Risks in Agriculture

One of the major sources of risk facing agriculture is caused by climate. The variation in yield caused by the climate variability from year to year can lead to instability of revenue. Variability of crop revenue is a primary source of business risk for a farm, comprising of fluctuating factors like yields and prices (Lameness et al., 2011). Agriculture risks arise due to uncertainty over factors determining returns to agricultural production (OECD, 2008). Anton et al. (2011) divided key risk faced by farmers into two types: production risk and price risk. Production risk tends to be less significant than price risk, but one can cause the other like weather events affecting production quality rather than quantity (Anton et al., 2011). Prices may fall to such an extent at harvest that the revenue is insufficient to repay the loan amount.

Decision making under uncertainty depends on the farmer's aversion to risk. The farmer's attitude and response to risk differs. Aiming (2010) divided farmers according to their risk preference. Farmers may be risk-averse, risk loving or risk neutral. The farmer's attitude under these different conditions affects his decision making. The attitude of the farmers differs and depends on their ability to take risks. Decision making in relation to production is sometimes complex and multifaceted, and decisions may be taken at several points in time during the production cycle (Jalota et al., 2007). Jalota et al. (2007) explained that the sequence of activities in agricultural production requires the farmers to make decisions before they know what the weather will look like for the coming season. Farmers cannot change anything once they have planted. The cost effect of their decision can be enormous.

Risk Management

Risk management is required to help producers make better decisions in risky situations. Risk management involves choosing among alternatives to reduce the impact of various types of risk (Lameness et al., 2011; Harwood et al., 1999). Farmers have different methods and strategies in managing risk. These strategies range from crop insurance, enterprise diversification, forward contracting, hedging, vertical integration, and revenue insurance. Farmers can also irrigate to mitigate the effect of limited precipitation in dryland farming if that option is available. Depletion of the water in the Ogallala Aquifer may be a major problem with this method. Liu et al. (2008) studied the selection of optimal crop insurance under climate variability and fluctuating market prices. Crop insurance contracts minimized loss for peanut producers at 75% of actual production history.

Data and Methodology

This study used county-level climatic information to estimate a quadratic function that shows the effect of precipitation variability on yield of crops grown in the Texas High Plains. The variance, coefficient of variation for yield, and revenue were estimated to analyze the effect of precipitation changes on yield and revenue. The study areas for dryland crops included Lynn County (dryland cotton), Deaf Smith County (dryland sorghum), and Hansford County (dryland wheat). The Farm Service Agency data of USDA were used to select the study area based on the total dryland acreage of the selected crops harvested in 2012. The data for irrigated corn were obtained from the Texas Cooperative Extension program called AgriPartners demonstration program from 1998 to 2007. Information about precipitation was obtained from the National Oceanic and Atmospheric Administration (NOAA). Yield and price information were obtained from National Agricultural Statistics Service (USDA- NASS) Quick Stats for the period of 1972 to 2012 for dryland cotton and dryland sorghum while the yield information for dryland wheat was obtained from 1973 to 2012.

Procedure

The yields of dryland crops (cotton, sorghum and wheat) were explained as a function of precipitation received during the growing season.

$$Y = f(X) \quad (1)$$

$$\text{Dryland yield} = b_o + b_1X + b_2X^2 \quad (2)$$

Growing season precipitation (X) is the amount of precipitation used in producing the dryland yield (Equation 2). Simetar© (Richardson et al., 2001) was used to develop a restricted OLS regression model without intercept. Coefficient of variation was used to explain the level of variation in yield, price, and the growing season precipitation. A sensitivity analysis was conducted at different precipitation levels that were determined at different probabilities of occurrence. Predicted yield and revenue deviations from the county average were estimated. Total direct expense is the average total direct expense incurred between 2008 and 2012 for each of the dryland crops. Direct expense information was obtained from the projected cost and return per acre budget for dryland cotton, dryland sorghum and dryland wheat for the Texas Panhandle. The average costs including the strip and module cost for cotton and average custom hauling cost for dryland sorghum and dryland wheat were \$260.61/ac, \$129.89/ac and \$117.68/ac respectively. The average strip and module cost for cotton is \$0.08/lb. The average custom hauling cost for dryland sorghum and dryland wheat are \$0.35/cwt and \$0.22/bu, respectively. The total strip and module cost for dryland cotton and the total custom hauling cost for dryland sorghum and dryland wheat vary with yield. The net margin received is the difference between the total value of product and total direct expenses.

A generalized relationship developed by Stewart and Peterson (2014) based on past studies was used to estimate the farm level yield of wheat and sorghum. A linear relationship between evapotranspiration (ET), transpiration/evapotranspiration (T/ET), transpiration ratio (TR) and harvest index (HI) was used to estimate yield (Equation 3). It was assumed that precipitation received equals evapotranspiration.

$$GY = ET \times \frac{T}{ET} \times \frac{1}{TR} \times HI \qquad (3)$$

For irrigated corn, the relationship between total water available and yield was examined. The irrigated corn yield was assumed as a function of total water (Equation 4). Ordinary least squares (OLS) regression was used to estimate the effect of total water on irrigated corn. Total water (TW) was made up of irrigation, precipitation and soil water present.

$$\mathrm{Yield} = \mathrm{b}_0 + \mathrm{b}_1\mathrm{TW} + \mathrm{b}_2\mathrm{TW}^2 \qquad (4)$$

The optimal profit is obtained by subtracting total cost from total value product. The profit maximizing water level is determined when the marginal value product equals marginal factor cost. The marginal value product is the first derivative of the total of value product while the marginal factor cost is the first derivative of the total cost.

The production cost of corn is made up of fixed cost and variable cost incurred during the production process. Since all irrigated growing activities in the High Plains use groundwater from the Ogallala Aquifer, variable cost varies with the amount of irrigation applied. The fixed cost (FC) is the total direct expense other than irrigation. The fixed cost of irrigated corn was obtained from the 2013 projected cost and return per acre budget for sprinkler irrigated corn in the Texas High Plains areas. The fixed cost was $504.11/ac. The variable cost (Irrigation cost) is made up of fuel cost (FULC), cost of lubrication, maintenance and repairs (LMR), labor cost (LC), and annual investment cost (AIC).

The information involving cost of irrigation was obtained from the economics of irrigation systems (Amosson et al., 2011). Low energy precision application (LEPA) at 350 pump lift was selected for the calculation of irrigation cost. The FULC is the product of natural gas price and the amount of natural gas (NG) used in million cubic feet (Mcf). NG is the amount of natural gas used to pump an acre-inch of water at 350ft of pumping lift which is assumed to equal 1/Mcf. The AIC is $1.06 (Qu, 2012), LMR and LC are $4.04 and $0.52 respectively

(Amos son et al., 2011). For this study, irrigation applied was obtained by subtracting precipitation received during the growing season from the total optimal water. In reality, soil water should be included in calculating irrigation water applied. Optimization tables were formed to find the optimal level of total water applied, irrigation water applied under at alternate prices for corn and natural gas at a given level of precipitation.

Results and Discussion

The amount of precipitation received during the growing season was used to explain yield variability in crops. Although irrigation was added as a supplement to reduce production risk in the case of irrigated corn, the impact of precipitation variability on total water available to crop, irrigation water applied, and profit were considered.

Dryland Sorghum

The ordinary least square regression (OLS) result relating dryland sorghum to growing season precipitation is shown in Table 1. The relationship between dryland yield and growing season precipitation from the unrestricted model is not significant at 5%. The result from the restricted model shows a significant relationship between dryland yield and growing season precipitation. The restricted model has no intercept because in dryland production, precipitation is the only source of water and if there is no precipitation, there will be no yield. The coefficient of determination from the restricted model is 90% meaning that 90% of the changes in the yield were explained by the changes in precipitation. An increase in precipitation by one inch may increase yield by 2.56cwt/ac. An increase in precipitation up to 19.48 inches will result in yield increase, additional precipitation beyond this point may decrease yield.

Forecasted Yields for Dryland Sorghum under Climate Variability

The estimated restricted regression coefficient for dryland sorghum mean response function (Equation 5**)** used growing season precipitation to predict future yield under different precipitation change scenarios is shown in Table 2. If the same climatic condition is repeated, there is a 30% chance of precipitation being less than 11.31 inches. Predicted yields have less variability than the actual yield and are more correlated with precipitation where X is the amount of growing season precipitation used by the crop.

$$\text{Dryland Sorghum Yield} = 262.56X - 6.75X^2 \qquad (5)$$

The predicted yield will increase above the county yield average by 2.52cwt/ac when an additional 2.33 inches of growing seasonal precipitation above the county average precipitation is received. The revenue level at a given county average price changed as the precipitation varied. Using the 5-year average price between 2006 and 2011($7.102), the county average revenue was $157.62/ac. The net margin using the county parameters was $26.81/ac. The net margin increased as the amount of precipitation available increased. The predicted net margin increases by $12.55/ac when the precipitation received increased by 1.13 inches above the county average precipitation. With 15.98 inches of precipitation, the revenue above the county average revenue increased by $17.02/ac. The predicted net margin will decrease by $7.63/ac as the precipitation received decrease by 2.33 inches below the county average precipitation.

Farm Level Analysis

Growing season precipitations below and above 50% probability of occurrence in Table 3 were used to estimate yield. Yield increases with an increase in precipitation up to the point where yield is maximized. At 40% probability of occurrence, the dryland yield should exceed 21.13cwt/ac. Production risk reduces as the amount of available precipitation increases. The addition of six inches of irrigation to 12.52 inches of precipitation received (Table 4) should increase the estimated yield by 18.88cwt/ac. An acre-inch of irrigation water will increase yield by at least 3.14cwt/ac.

Risk Analysis

The study period of 1972-2012 was divided into four sub-periods where coefficient of variation for precipitation and yield for each period were considered. The coefficient of variation for precipitation and dryland sorghum yield moved in the opposite direction between 1972-1981 and 1982-1991 (Figure 1).

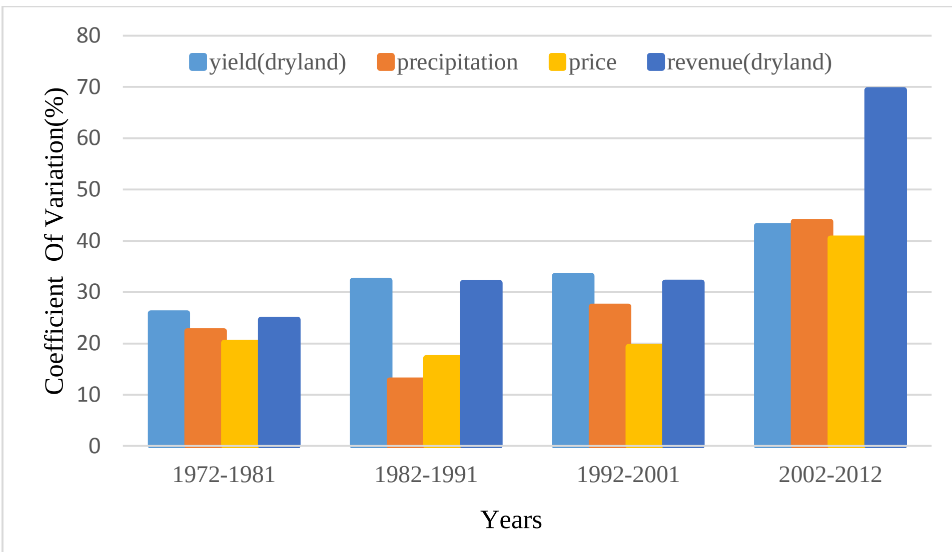

Figure 1: Coefficient of variation for dryland sorghum, growing season precipitation, price and revenue.

The coefficient of variation for precipitation declined from 1972-1981 to 1982-1991 period by 9.59%. A decline in the coefficient of variation for precipitation reduces risk that can arise from precipitation variability and favors dryland yield increase by 5.14 cwt/ac (Figure 2).

However, the increase in coefficient of variation for precipitation by 30.88% from 1982-1991 to 2002-2012 period resulted in the decline of average dryland yield by 4.18 cwt/ac (Figure 2).

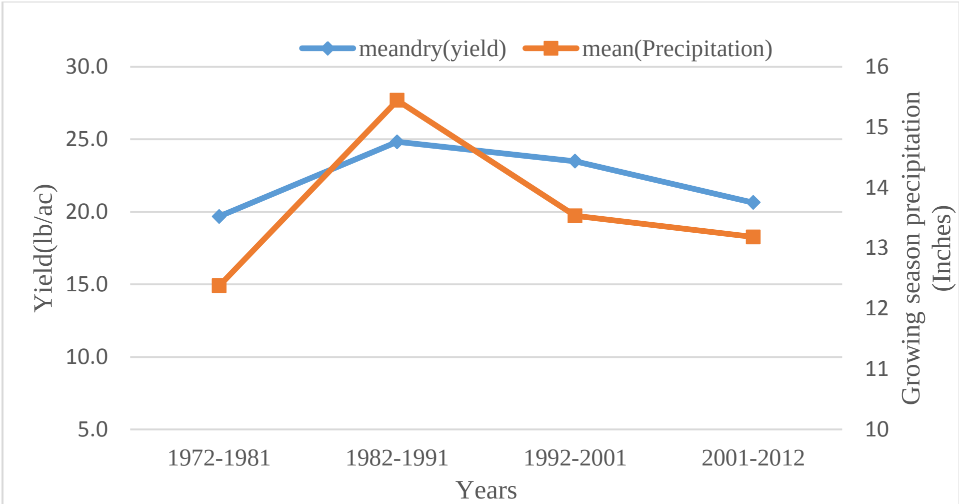

Figure 2: Average dryland sorghum yield and growing season precipitation received from 1972-2012. Values were calculated from data obtained from USDA- NASS and NOAA).

Dryland Wheat

The model result shows the relationship between dryland wheat yield and growing season precipitation. The ordinary least square regression (OLS) result relating dryland wheat to precipitation is shown in Table 5. Precipitation received during the growing season was used to explain variation in yield. The R^2 value of the unrestricted model was 50%, but the estimates are not significant at 5%. The result from the restricted model shows a significant relationship between yield and precipitation. The unrestricted model has an R^2 value of 93% when the intercept was removed. It means that 93% of the changes in the yield were explained by the changes in precipitation. Most of the dryland wheat yield is grazed by cattle.

Forecasted Yields for Dryland Wheat under Climate Variability

The estimated restricted regression coefficient (Equation 6) for the dryland wheat response function using precipitation was used to simulate future yield under different precipitation change scenarios. The probability of having precipitation around the county precipitation mean is shown in Table 6. Yields predicted have less variability than the actual yield and are more correlated with precipitation.

$$\text{Dryland Wheat Yield} = 1.92\text{X} - 0.02\text{X}^2 \quad (6)$$

Predicted yield will increase above the county average by 3.77 bu/ac if the amount of precipitation received increases by 2.74 inches above the county average precipitation. Revenue at each level of precipitation was a product of 5-years average price between 2008 and 2012 and the predicted yield. The county average revenue is $134.27/ac. The net margin using the county parameters is $12.00/ac. The net margin will increase as the amount of precipitation available increases. The net margin above the county average will increase by $23.44/ac if the growing season precipitation increases by 2.74 inches. The predicted net margin will decrease by $21.08/ac when the precipitation received decreased by 2.74 inches below the county average precipitation.

Farm Level Analysis

Farm level yield was predicted using Equation 4.Growing seasonal precipitation at 40%, 50% and 60% probability of occurrence in Table 7 were used as evapotranspiration. Yield increases as the precipitation increases. At 50% probability, estimated yield exceeds 34.41 bu/ac. Production risk reduced as the precipitation increased. The addition of six inches of irrigation to 11.84 inches of precipitation received (Table 8) should increase the estimated yield by 27.33 bu/ac,

Risk Analysis

The study period of 1973-2012 was divided into four sub-periods where the coefficient of variation for precipitation and yield for each period were considered. The coefficients of variation for precipitation and wheat yield moved in the opposite direction between 1973-1982 and 1983-1992 (Figure 3). The coefficient of variation for precipitation increased by 34.31% from the 1973-1982 to 2003-2012 period while the coefficient of variation for dryland wheat yield declined by 3.57%. The higher the coefficient of variation for precipitation, the greater the risk faced by farmers.

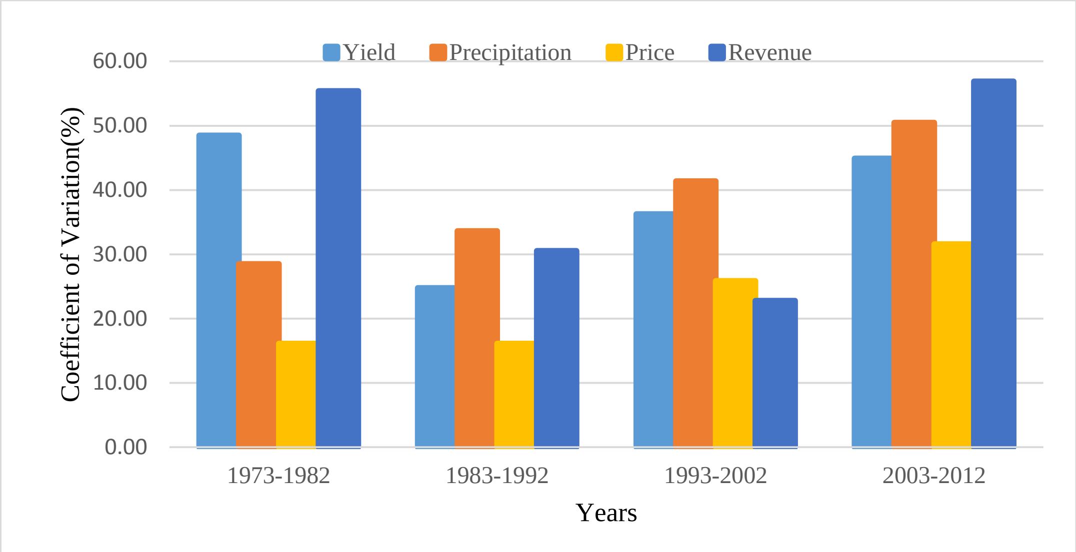

Figure 3: Coefficient of variation for dryland wheat, growing season precipitation, price and revenue.

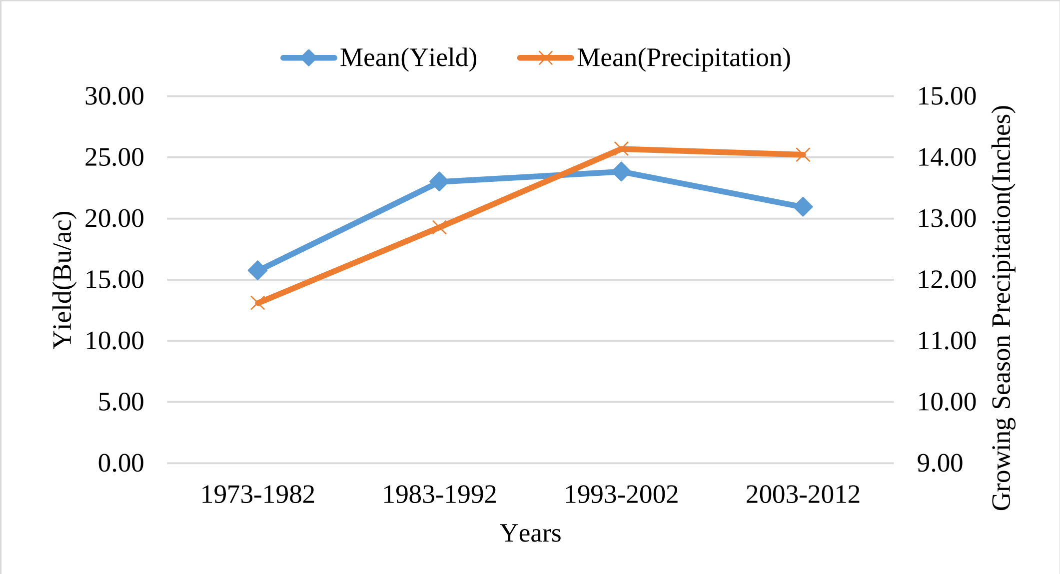

Figure 4**:** Average dryland wheat yield and growing season precipitation received from 1973-2012. Values were calculated from data obtained from USDA- NASS and NOAA).

The coefficient of variation for precipitation increased by 9.07% (Figure 3) between 1993-2002 and 2003-2012 period while the average dryland yield decreased by 2.88bu/ac (Figure 4).

Dryland Cotton

The ordinary least square regression (OLS) result relating dryland cotton to growing season precipitation is shown in Table 7. The coefficient of determination increased from 5% to 87% when the model was without an intercept because no yield occurs at zero precipitation. The estimates of the unrestricted model are not significant at 5%. The result from the restricted model shows a more significant relationship between dryland yield and growing season precipitation as the estimates of the precipitation and precipitation squared are significant at 1%.

The coefficient of determination of the restricted model is 87%. It means that 87% of the changes in the yield were explained by the changes in precipitation. Minimum amount of precipitation has to be supplied to the dryland cotton before the crop can be productive. An increase in precipitation beyond this point by an inch may increase yield by 34.64 lb/ac until the yield is maximized. The dryland cotton yield is maximized at 21.62 inches and additional precipitation beyond this point may decrease yield.

Forecasted Yields for Dryland Cotton under Climate Variability

Precipitation change around the 40-year precipitation average was used to predict the yield (Equation 7) in comparison to the actual average yield from 1972-2012 (Table 8). The probability of having precipitation around the county precipitation mean is shown in Table 8. If the same climatic condition is repeated, there is a 30% probability of having precipitation less than 12.25 inches. Predicted yields have less variability than the actual yield and are more correlated with precipitation (the correlation coefficient between the predicted yield and precipitation was 0.82).

$$\text{Dryland Cotton Yield} = 35.46X - 0.82X^2 \qquad (7)$$

where X is the amount of the growing season precipitation used by the dryland cotton. The predicted yield using the county average precipitation was 347.56 lb/ac, which was 17.51 lb/ac more than the actual average yield. At 17.78 inches of precipitation, the predicted yield increased by 41.25 lb/ac above the county average. The revenue at each level of precipitation at a given county average price changed as the precipitation varied. The county average revenue was $223.46/ac. The county average revenue increased from $223.46/ac to $ 251.39 /ac when average precipitation increased from 15.01 inches to 17.78 inches. The total direct expense varies at different levels of yield as the average strip and module cost depends on the level of yield harvested.

The net margin using the county parameters resulted in a loss of $36.95/ ac. The losses decreased as the amount of precipitation received increased. Predicted net margin decreased by $18.24/ac when the precipitation received increases above the average precipitation by 1.34 inches. Net margin decreases by $24.59/ac when precipitation increases by 2.77 inches from 15.01 inches to 17.78 inches (Table 8). The predicted loss increases by $11.22/ ac as the precipitation received decrease by 2.77 inches below the county average precipitation.

Price risk is mitigated by crop insurance and direct payments from the government under various programs to reduce revenue variation. Under the 2008 Farm Bill Act, the direct payment gave fixed payment to farmers regardless of crop failure or price risk and was based off of historical production. The 2014 Farm Bill has repealed Direct Countercyclical Payments and replaced these programs with Price Loss Coverage (PLC) and Agriculture Risk Coverage (ARC). Upland cotton producers are not eligible for PLC or ARC, but they are eligible for a new crop insurance product under Title XI—the Stacked Income Protection Plan (STAX) (Farm Service Agency, 2014). The USDA Economic Research Service (2014) stated that the Stacked Income

Protection Plan (STAX) provides revenue insurance policies to producers of upland cotton beginning with the 2015 crop, in place of coverage for cotton under the new Price Loss Coverage (PLC) and Agriculture Risk Coverage (ARC) programs.

Irrigated Corn

Irrigated corn is a high water use crop. Majority of the corn produced in the Texas High Plains are supported by irrigation due to limiting precipitation, which does not support the dryland corn production. The coefficient of determination for the restricted equation is shown in Table 9. The coefficient of determination is 96%. It means that 96% of the variation in irrigated corn yield is caused by total water available to the crop. The coefficient of determination is high because the study focused only on water factor and considered other variables constant. Irrigated corn yield is maximized at 38.39 acre-inches of total water. Other factors that may affect irrigation water available are the sale price of corn and natural gas. The profit maximizing level of available total water in acre-inches for irrigated corn grain production at different fuel prices and corn sales price is shown in Table 10.

Although a farmer does not have total control over precipitation received, a farmer can decide on how much supplementary irrigation water to apply based on irrigation well capacity. The amount of supplementary irrigation water needed depends on precipitation received during the growing season. Farmers will be eager to pump irrigation water to make up for precipitation deficiency at a higher corn price and low energy price. At an energy price of $4.5/Mcf and corn market price of $8.5/bu, a farmer will be able to maximize profit by using 34.55 acre-inches of total water (Table 10) compared to a low corn sales price and a high energy price. At $8/Mcf and corn sales price of $6/bu, 30.65 acre-inches of total water will be used.

In Hansford County, the average precipitation received during the growing period from 1972 through 2012 was 12.36 inches with a standard deviation of 3.99. The coefficient of variation for precipitation during this period was 32.32%. The profit maximizing irrigation level in acre-inches for corn grain production is shown in Table 11. At 12.36 inches of precipitation, the amount of irrigation water use increases as the price of corn increases and the price of natural gas decreases subject to irrigation water availability. If 12.36 inches of precipitation is received, at $4/Mcf of natural gas and $6.5/bu of corn, a farmer will be able to maximize profit by applying 21.15 acres-inches of irrigating water (Table 11). At same corn sales price and higher natural gas price, the farmer will be using less amount of irrigation to maximize profit. At a natural gas price of $8/Mcf and corn sales price of $6.5/bu, 18.93 inches of irrigation water will be added.

The optimal profit for corn grain production under alternate combinations natural gas and corn price is shown in Table 12. Applying growing season precipitation from Hansford County, at $4.5/Mcf of natural gas and $6.5/bu of corn grain, profit will be maximized at $614.34/ac. The profit declines as the natural gas price increases from $4/Mcf to $9/Mcf. At a natural gas price of $6/Mcf and corn sales price of $6.5/bu, the optimal profit declines by $30.56/ac.

Profitability at Different Levels of Precipitation

The effect of precipitation variation was examined at ± 25% of the growing season average precipitation of Hansford County. The county growing season average precipitation at a 25% reduction will be 9.67 inches and an increase in the growing season average precipitation by 25% will be 15.05 inches. The optimal profit for corn grain production in the Texas High Plains at alternate combinations of natural gas and corn price at 9.67 inches and 15.03 inches of precipitation are shown in Table 13 and Table 14 respectively. Reduction in growing season precipitation increases the irrigation water required to meet crop evapotranspiration by 2.69 inches. At $4/Mcf of natural gas and $5/bu, reduction in the precipitation level by 2.69 inches will reduce profit from $319.15/ac (Table 12) to $293.23/ac (Table 13). Increase in the county average season precipitation level by 25% will increase optimal profit. An increase in growing season precipitation will reduce the amount of irrigation applied and irrigation cost incurred. At $5/Mcf of energy price and $6.5/bu of corn, increase in precipitation by 2.69 inches will increase profit from $603.98/ac (Table 12) to $632.59/ac (Table 14).

Changes in Irrigation Water Demand Due to Precipitation Fluctuation

The amount of precipitation received by a county determines the amount of irrigation water needed to meet the crop water requirements. The ability to meet the irrigation water requirement depends on the quantity of water in different irrigation wells across different farms in the county. Variation in precipitation around the county average precipitation received during the growing season can be used to estimate the amount of irrigation water required in the future. Assuming that the same acreage (using 2012 Farm Service Agency harvested acreage data) will be cultivated for the next 50 years and the probability of precipitation received for the next 50 years revolves below and above the county's growing season average precipitation by 25% for the last 40 years. Considering soil water change as constant, the crop water requirement will be used to estimate the amount of supplementary irrigation water required in the future. Using the crop evapotranspiration for Carson County (Masonry et al., 2003), the evapotranspiration for irrigated corn was 31 inches, 26.8 inches for irrigated sorghum, 30.3 inches for irrigated wheat and 27.4 inches for irrigated cotton (Kerns et al., 2011).

The estimated irrigation water required in acre-feet by county for irrigated crops at different levels of precipitation is shown in Table 15. Additional 117,609 acre feet of irrigation water will be needed in the Deaf Smith County for irrigated sorghum if there is a 25% decrease in the average seasonal precipitation received for the next 50 years. The additional irrigation water that will be required in Hansford County for irrigated corn is 853,056 ac-ft. if the precipitation received for the next 50 years will decrease by 3.09 inches from the growing season average. The supplementary future irrigation water requirement will decrease as the amount of precipitation received increase.

Conclusion

The restricted models showed a significant relationship between yield and the growing season precipitation when the intercept was removed. The restricted models have a higher R^2 value than the actual fitness of the observed data. The study shows that dryland crops face a production risk as precipitation variability increases, because the higher the coefficient of variation for precipitation, the greater the risk faced by farmers. A decline in the coefficient of variation for precipitation by 9.59% favored the dryland sorghum yield increase by 5.14 cwt/ac from 1972-1981 to 1982-1991. At a natural gas price of $4.5/Mcf and corn sales price of $7/bu, variation in the Hansford county seasonal precipitation by ±2.69 inches changes the optimal profit by ±$27.48/ac. In the Deaf Smith County, an additional 117,609 ac-ft. of irrigation water will be needed for irrigated sorghum if there is a 25% decrease in the average seasonal precipitation received for the next 50 years.

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Table 1: Result showing restricted and unrestricted ordinary least square result relating dryland sorghum to growing season precipitation.

	Unrestricted OLS			Restricted OLS		
Independent Variable	Estimate	Standard Error	p-Value	Estimate	Standard Error	p-Value
Intercept	12.82	8.78	0.1531			
Precipitation	0.96	1.18	0.4203	2.63	0.29	0.0000
Precipitation squared	-0.02	0.04	0.6347	-0.07	0.02	0.0000
R^2	0.06			0.90		

Table 2: The predicted dryland sorghum yield, revenue and net margin at different levels of growing season precipitation.

	Probability of occurrence				
	0.3	0.4	0.5	0.6	0.7
Precipitation(inches)	11.31	12.52	13.65	14.77	15.98
Number of years with less precipitation	11	15	20	25	29
Yield(cwt/ac) at each level of precipitation	21.06	22.29	22.19	24.05	24.71
Yield Difference from the county Average (cwt/ac)	(1.13)	0.09	0.00	1.86	2.52
Revenue($/ac)	149.59	158.29	157.62	170.82	175.52
Change in Revenue($/ac)	(8.03)	0.67	0.00	13.20	17.90
Total direct expense ($/ac)	130.41	130.84	130.81	131.46	131.69
Net margin($/ac)	19.18	27.45	26.81	39.36	43.83

Table 3: The predicted dryland sorghum yield, revenue and net margin at different levels of growing season precipitation.

	Probability of occurrence				
	0.3	0.4	0.5	0.6	0.7
Precipitation(inches)	11.31	12.52	13.65	14.77	15.98
Number of years with less precipitation	11	15	20	25	29
Yield(cwt/ac) at each level of precipitation	21.06	22.29	22.19	24.05	24.71
Yield Difference from the county Average (cwt/ac)	(1.13)	0.09	0.00	1.86	2.52
Revenue($/ac)	149.59	158.29	157.62	170.82	175.52
Change in Revenue($/ac)	(8.03)	0.67	0.00	13.20	17.90
Total direct expense ($/ac)	130.41	130.84	130.81	131.46	131.69
Net margin($/ac)	19.18	27.45	26.81	39.36	43.83

Table 4: Estimated farm level yield for dryland and irrigated sorghum using evapotranspiration, transpiration/evapotranspiration, transpiration efficiency and harvest index values for grain sorghum.

	ET (inches)	ET(kg)	T/ET	TR	HI	Yield (kg/ha)	Yield (cwt/ac)	Yield (bu/ac)
Precipitation Only	12.52	3,180,080	0.55	258	0.35	2,372.73	21.13	41.68
	13.65	3,467,100	0.57	256	0.36	2,779.10	24.75	48.82
	14.77	3,751,580	0.58	253	0.37	3,182.17	28.34	55.90
Precipitation + 6 inches of irrigation	18.52	4,704,080	0.6	245	0.39	4,492.88	40.01	78.93
	19.65	4,991,100	0.63	237	0.42	5,572.34	49.63.	97.89
	20.77	5,275,580	0.65	235	0.45	6,566.41	58.48	115.36

Table 5: Descriptive statistics of dryland wheat yield, price and revenue from 1973-2012 for Hansford county.

	Precipitation(Inches) (October-June)	Yield (bu/ac)	Price ($/bu)	Revenue ($/ac)
Mean	13.16	20.88	3.70	75.13
Standard Deviation	5.23	8.29	1.34	40.52
Maximum	26.16	41.00	7.58	262.40
Minimum	4.85	7.50	2.15	23.44
CV (%)	39.76	39.71	36.30	53.94

Table 6. Restricted and Unrestricted OLS Regression Results of Dryland Wheat Yield Response to Growing Season Pricipitation

	Unrestricted OLS			Restricted OLS		
Independent Variable	Estimate	Standard Error	p-Value	Estimate	Standard Error	p-Value
Intercept	10.67	6.17	0.0923			
Precipitation	0.44	0.89	0.6263	1.92	0.23	0.0000
Precipitation squared	0.02	0.03	0.4503	-0.02	0.013	0.0749*
R^2	0.49			0.93		

Table 7: Restricted and unrestricted ordinary least square result relating dryland cotton to growing season precipitation.

	Unrestricted OLS			Restricted OLS		
Independent Variable	Estimate	Standard Error	p-Value	Estimate	Standard Error	p-Value
Intercept	272.11	154.65	0.0868			
Precipitation	2.14	19.46	0.9132	35.46	4.61	0.0000
Precipitation squared	0.10	0.57	0.8591	-0.82	0.24	0.0000
R^2	0.05			0.87		

Table 8: The predicted dryland cotton yield, revenue and net margin at different levels of growing season precipitation.

	Probability of Occurrence				
	0.3	0.4	0.5	0.6	0.7
Precipitation(inches)	12.25	13.68	15.01	16.35	17.78
Number of years with less precipitation	11	15	20	25	29
Yield(lb/ac) at each level of precipitation	311.26	331.59	330.05	360.60	371.30
Yield Difference from the county Average(lb/ac)	(18.79)	1.54	0.00	30.55	41.25
Revenue($/ac)	210.74	224.51	223.46	244.15	251.39
Change in Revenue($/ac)	(119.31)	(105.54)	(106.59)	(85.90)	(78.66)
Total direct expense ($/ac)	258.91	260.54	260.41	262.86	263.71
Net margin($/ac)	(48.17)	(36.03)	(36.95)	(18.71)	(12.32)

Table 9: Restricted and unrestricted OLS result relating irrigated Corn to precipitation.

	Unrestricted OLS			Restricted OLS		
Independent Variable	Estimate	Standard Error	p-Value	Estimate	Standard Error	p-Value
Intercept	-21.75	55.05	0.6934			
Precipitation	12.09	3.42	0.0006	10.75	0.53	0.0000
Precipitation squared	-0.16	0.05	0.0029	-0.14	0.02	0.0000
R^2	0.14			0.96		

Table 10: Profit maximizing level of available total water in acre-inches for corn grain production under alternate combinations of natural gas and corn price.

	Price of Corn ($/bu)								
$/Mcf	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00
4.00	31.91	32.54	33.06	33.51	33.89	34.22	34.51	34.77	34.99
4.50	31.54	32.21	32.76	33.23	33.63	33.98	34.29	34.55	34.79
5.00	31.18	31.88	32.46	32.95	33.37	33.74	34.06	34.34	34.59
5.50	30.82	31.55	32.16	32.68	33.12	33.50	33.83	34.13	34.39
6.00	30.46	31.22	31.86	32.40	32.86	33.26	33.61	33.92	34.19
6.50	30.10	30.89	31.56	32.12	32.60	33.02	33.38	33.70	33.99
7.00	29.74	30.57	31.26	31.84	32.34	32.78	33.16	33.49	33.79
7.50	29.38	30.24	30.96	31.56	32.08	32.54	32.93	33.28	33.59
8.00	29.01	29.91	30.65	31.29	31.83	32.30	32.71	33.07	33.39
8.50	28.65	29.58	30.35	31.01	31.57	32.05	32.48	32.85	33.19
9.00	28.29	29.25	30.05	30.73	31.31	31.81	32.25	32.64	32.99

Table 11: Profit maximizing irrigation level in acre-inches for corn grain production under alternate combinations of natural gas and corn price.

	Price of corn ($/bu)								
$/Mcf	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00
4.00	19.55	20.18	20.70	21.15	21.53	21.86	22.15	22.41	22.63
4.50	19.18	19.85	20.40	20.87	21.27	21.62	21.93	22.20	22.43
5.00	18.82	19.52	20.10	20.59	21.02	21.38	21.70	21.98	22.23
5.50	18.46	19.19	19.80	20.32	20.76	21.14	21.47	21.77	22.03
6.00	18.10	18.86	19.50	20.04	20.50	20.90	21.25	21.56	21.83
6.50	17.74	18.53	19.20	19.76	20.24	20.66	21.02	21.34	21.63
7.00	17.38	18.21	18.90	19.48	19.98	20.42	20.80	21.13	21.43
7.50	17.02	17.88	18.60	19.20	19.72	20.18	20.57	20.92	21.23
8.00	16.65	17.55	18.30	18.93	19.47	19.94	20.35	20.71	21.03
8.50	16.29	17.22	17.99	18.65	19.21	19.69	20.12	20.49	20.83
9.00	15.93	16.89	17.69	18.37	18.95	19.45	19.89	20.28	20.63

Table 12: Maximum profit in dollar per acre for corn grain production under alternate combinations natural gas and corn price.

	Price of corn ($/bu)								
$/Mcf	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00
4.00	319.15	420.58	522.52	624.85	727.48	830.36	933.44	1036.69	1140.06
5.00	299.96	400.73	502.12	603.98	706.21	808.74	911.52	1014.49	1117.63
6.00	281.50	381.54	482.32	583.66	685.45	787.60	890.04	992.72	1095.60
7.00	263.76	363.01	463.12	563.90	665.21	766.94	869.02	971.38	1073.97
8.00	246.75	345.13	444.52	544.70	645.49	746.77	848.45	950.46	1052.74
9.00	230.45	327.91	426.53	526.05	626.28	727.07	828.33	929.96	1031.91

Table 13: Maximum profit in dollar per acre for corn grain production under alternate combinations natural gas and corn price at 9.67 inches of precipitation.

	Price of corn ($/bu)								
$/Mcf	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00
4.00	293.23	394.66	496.60	598.93	701.57	804.45	907.53	1010.77	1114.15
4.50	282.20	383.31	484.98	587.08	689.52	792.23	895.16	998.27	1101.53
5.00	271.35	372.12	473.51	575.37	677.60	780.13	882.91	985.88	1089.02
5.50	260.69	361.10	462.18	563.79	665.81	768.15	870.76	973.59	1076.61
6.00	250.20	350.24	451.01	552.36	654.15	756.30	858.74	961.42	1064.29
6.50	239.89	339.54	439.99	541.06	642.62	744.56	846.82	949.34	1052.08
7.00	229.77	329.01	429.12	529.90	631.21	732.95	835.02	937.38	1039.97
7.50	219.82	318.64	418.40	518.88	619.94	721.45	823.33	925.52	1027.96
8.00	210.06	308.44	407.83	508.01	608.79	710.08	811.75	913.76	1016.04
8.50	200.47	298.40	397.41	497.26	597.78	698.82	800.29	902.12	1004.23
9.00	191.07	288.52	387.14	486.66	586.89	687.69	788.94	890.57	992.52

Table 14: Maximum profit in dollar per acre for corn grain production under alternate combinations natural gas and corn price at 15.03 inches of precipitation.

	Price of corn ($/bu)								
$/Mcf	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00
4.00	345.07	446.50	548.44	650.77	753.40	856.28	959.36	1062.60	1165.98
5.00	328.58	429.34	530.73	632.59	734.82	837.35	940.13	1043.10	1146.24
6.00	312.81	412.85	513.62	614.97	716.76	818.91	921.35	1024.02	1126.90
7.00	297.76	397.00	497.12	597.90	699.21	800.94	903.02	1005.37	1107.97
8.00	283.44	381.82	481.21	581.39	682.18	783.46	885.14	987.15	1089.43
9.00	269.84	367.29	465.91	565.44	665.67	766.46	867.71	969.35	1071.30

Table 15: Estimated irrigation water required in acre-feet by county for irrigated crop at different levels of precipitation.

Precipitation scenarios	County	Crop	Acreage (Acres)	Irrigation Required (Inches)	Irrigation water required for the next 50 years at average precipitation (ac-ft.)	Change in irrigation water at ± 25% of average season precipitation (ac-ft.)
Change in precipitation by ± 25% of the county average growing season precipitation	Lynn	Irrigated cotton	74,007.30	12.39±3.75	3,820,627	1,157,135
	Deaf Smith	Irrigated Sorghum	8,271.40	13.15±3.41	453,204	117,609
	Hansford	Irrigated Wheat	39,583.35	17.14±3.29	2,826,911	542,622
	Hansford	Irrigated Corn	66,256.79	18.64±3.09	5,145,944	853,056