Use of Expected Weather Information on Dryland Wheat Production in Texas High Plains

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ABSTRACT

Winter wheat (*Triticum aestivum L.*) is a commonly planted dryland crop in the Texas High Plains. The Texas High Plains is classified as a semiarid region with high degrees of variation in the amount of rainfall received in this area. Conditions of high climatic variability coupled with frequent droughts account for the low crop yields obtained in this region. Proper rainfall predictions before any production season provide valuable information to farmers to benefit from good years or reduce losses in bad years. A simulation study was conducted to evaluate the economic effects of management practices under below and above average rainfall scenarios. Stochastic dominance with respect to a function (SDRF) was used to introduce risk and take into account the inherent variability of dryland production systems. Expected net revenues above variable costs were compared across different management practices. Predicted benefits to producers by adjusting crop management practices to anticipated weather was found to be in the range of $18 to $32 million per year. The results indicate that expected seasonal rainfall information has a major effect on the profitability of dryland wheat producers.

KEYWORDS: Dryland Agriculture, Stochastic Dominance, Weather Information

INTRODUCTION

Climate is one of the most important uncontrolled factors affecting agriculture. The United States agriculture experiences vast changes in terms of droughts, storms, extreme heat and cold waves, in almost any given year. Over the past decade there have been increased efforts by researchers across the globe to demonstrate the utility of climate forecasts in climate sensitive areas like agriculture (Ritchie and Alagarswamy 2002, Jones et al. 2000, Riha et al. 1996). El Niño/ Southern Oscillation (ENSO) phenomenon is considered to be the main source of interannual climate variability in many parts of the world (Baethgen 1985). There is substantial literature which provides ample information on ENSO basics and decision theories applied to weather and climate forecasting cases (see Orlove and Tosteson 1999, Katz and Murphy 1997, Glantz 1996). According to the National Oceanic and Atmospheric Administration (NOAA), the 1998-99 La Niña event was responsible for agricultural losses of more than $2 billion in the United States when compared to $1.5 billion in agricultural damage from the 1997-98 El Niño cycle (NOAA 1999). Research at Texas A&M University suggested that 70% of monthly variances in Texas weather might be caused by outside effects, which implies that La Niña has a significant impact on Texas climate trends (TWRI 1996).

Seasonal climate forecasts assist farmers in managing cropping systems, either in short-term tactical decisions or long-term strategic decisions (Carberry et al. 2000). The effective applications of seasonal forecasts on crop productivity and the impact on farm level decision making is well documented in the scientific literature (Chen et al. 2002, Jochec et al. 2001, Mjelde and Penson 2000). International Research Institute for Climate Prediction (IRI) regularly offers updates and discussion on seasonal forecast information for various parts of the world. Forecast assessment by IRI can be accessed through Internet by using the web link http://iri.columbia.edu/climate/ forecast/ net_asmt. With increased awareness and availability of the current technologies to more accurately forecast weather related events, emphasis has been directed to how best utilize climatic information to reduce losses or to enhance profits for various sectors of the economy. The possibility of adjusting management practices in accordance with the expected weather conditions of the next season offers ample opportunities to dryland producers. Hence, the focus of this paper is on how to (i) select the appropriate winter wheat management practices (planting dates, plant population and fertilization practices) that can enhance the profitability/reduce losses under conditions of climate change and (ii) identify the economic benefits of adjusting winter wheat to seasonal rainfall expectations.

METHODS

Model Specifications and Simulating Climatic Variability

As actual field experimentation is time consuming and the choices available to researcher are limited, the best approach is to use a crop simulation model in conjunction with climatic data to simulate crop yields. Simulation models in combination with crop inputs can determine the uncertainty associated with various management practices (Thronton and Wilkens 1998, Lansigan et al. 1997). CroPMan version 3.1 (Crop Production and Management Model), as developed at the Blackland Research and

Extension Center, Temple, Texas was used in the present study to simulate crop yields. CroPMan is a computer framework designed to simulate the production and resource consequences to crop management. Management practices that can be simulated using CroPMan include, but are not limited to, planting date, crop maturity, plant population, crop type and rotation sequence. CroPMan uses actual daily weather data from established weather stations and statistically simulates random weather patterns for future season crop yields.

Cropping practices that might be used to take advantage of seasonal rainfall conditions would include crop choice, planting density, planting date and fertilization rates. The suitable planting and harvesting dates for the High Plains were identified using the Texas commodity calendar published by the Texas A&M University. Effects of planting dates were tested in weekly intervals from September 1 to October 28, and planting densities were tested in 10,000 plants/acre increments from 300,694 plants/ac to 450,694 plants/ac. Impacts of elemental nitrogen and fertilizer blends of 22-08-02, and 18-08-04 on winter wheat profitability were also studied. The fertilizer blends were increased at an interval 25 lbs/ac from 75 to 300 lbs/ac whereas elemental N was increased at 10 lbs interval to 60 lbs/ac. The prices for fertilizer blends were calculated manually based on nutrient grade.

A combined effort was made in simulating the effects of variable climatic conditions on dryland winter wheat production in the Texas High Plains, in which the actual meteorological data was integrated with the CroPMan software. The weather input file (*.dly) in CroPMan utilizes the daily weather values from 1956 to 2003. These data include daily values for precipitation (mm), maximum and minimum temperatures (ºC), solar radiation (MJ/m^2), relative humidity (%), and wind speed (m/s). The Perryton, Spearman, and Hereford weather station databases of the National Weather Service represented the baseline scenario. Actual precipitation data for these weather stations from 1991 to 2003 winter wheat growing season was collected, and the maximum and minimum amounts were identified. CroPMan weather input values were changed proportionately to the observed maximum and minimum rainfall levels to reflect the effects of climate change. The assumption made for this scenario was, the minimum rainfall level represents the driest climate (below normal) and the maximum rainfall represents the wettest climate (above normal). Under these changed weather scenarios, CroPMan simulations were ran for different management practices (planting date, plant population, fertilization, etc.,) to obtain the simulated yield.

Decision Making Under Uncertainty

Understanding risk in dryland farming is important in identifying sources of uncertainty and helps farmers in developing strategies for mitigating risk. The basic linkages between crop production due to climatic variability and its associated output are presented in Figure 1. Because of the changing climatic conditions, the VMP_x curve shifts. (It would shift outward in the case of good rainfall and would shift inwards in the case of drought.) Panel (d) in Figure 1 represents a drought condition scenario. Accordingly, the profit function also shifts and it is represented in panel (c) of Figure 1. This study used stochastic dominance with respect to a function (SDRF) to select the best combination of crop management strategies for producers with different risk preferences. SDRF is an evaluative criterion which orders uncertain action choices for classes of

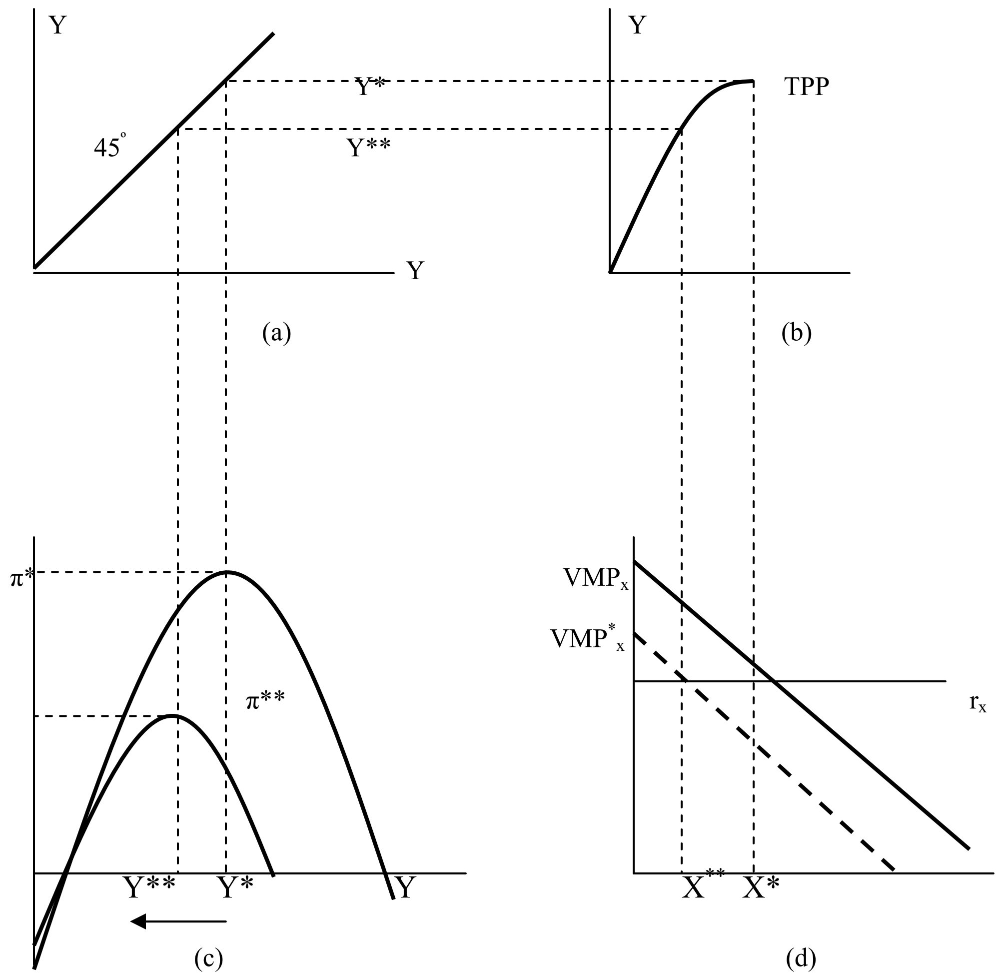

Fig 1. Linkages between production function and output relationship under changing weather conditions

decision makers defined by lower and upper bounds on the absolute risk aversion function (King and Robinson 1981). If a decision maker must decide between two risky alternatives, say M_1 and M_2 with CDF's given by α(φ) and β(φ) respectively, and if the expected utility of β(φ) is greater than the expected utility of α(φ), then M_2 is preferred over M_1 by the decision maker.

Mathematically, the absolute risk aversion coefficient can be defined as:
$r(\varphi) = -\mu''(\varphi) / \mu'(\varphi)$, where μ represents the decision maker's utility function and φ is income or wealth and $\mu''(\varphi)$ and $\mu'(\varphi)$ are the first and second derivatives of a utility function μ (φ). According to Meyer (1977), the solution requires the identification of a utility function μ (φ), which minimizes

$$\int_0^1 \{\alpha(\varphi) - \beta(\varphi)\}\mu'(\varphi)d(\varphi) \text{ subject to the constraint}$$

$$r_L(\varphi) \leq -\mu''(\varphi)/\mu'(\varphi) \leq r_U(\varphi) \text{ for all } \varphi \text{, and } \mu'(\varphi) > 0 \text{ for all } \varphi$$

Where r_L (φ) and r_U (φ) represents the lower and upper bounds of r (φ)

Stochastic dominance with respect to a function analysis was conducted using SIMETAR (Simulation for Applied Risk Management). For practical purposes, three alternative risk intervals for the dryland cropping systems of the Texas High Plains in the range –0.0003 to 0.0006 (risk neutral -0.0003 to 0.001; slightly risk averse 0.00 to 0.0003; strongly risk averse 0.0003 to 0.0006), similar to those used by Segarra et al. (1991) were used in the present study. Average variable costs for dryland winter wheat were based on District 1 and 2 of Texas Cooperative Extension budgets. By multiplying the simulated yields by the appropriate price ($3.00 per bushel), the expected gross revenues were derived. Net returns per acre were obtained by subtracting the variable costs from gross revenues. The simulated data was used to investigate different management strategies in order to derive stochastically efficient management practices.

RESULTS AND DISCUSSION

A total of 130 management practices were simulated under alternative production practices for winter wheat (based on all combinations of 16 planting densities, ten planting dates, four fertilizer rates, three fertilizer types, two rainfall scenarios, and 27 best management practices). It is important to point out that the results presented in this paper are not based on a whole farm approach but rather per acre.

Winter wheat yield levels at Ochiltree County as influenced by planting density ranged from 17.71 bu/ac to 29.86 bu/ac across all weather conditions. This study's findings showed that rainfall changes would be expected to have a strong influence on winter wheat yields at Ochiltree County. Population densities of 450,694 plants/ac (Tables 1 and 2) resulted in higher returns for both below and above normal rainfall conditions. However, comparing the "SDRF ranking" of plant densities to those obtained under "the average net return ranking" approach, it is evident that the rankings were different. Under SDRF approach, planting density of 430,694 plants/ac is the preferred choice for Ochiltree County under below rainfall conditions. Winter wheat producers are not only concerned with the "average" performance of their practices, but also take into consideration of the inherent variability of dryland production systems. For this reason, SDRF ranking was considered superior to average net return ranking approach.

Among the different factors that can be controlled by producer, date of planting is probably the most important for winter wheat (Campbell et al. 1991). Winter wheat is commonly planted over a wide range of dates in the Texas High Plains. The majority of planting occurs in the months of September and October. Summers in this region are usually dry and the timing of rains in early fall and winter play an important role in determining the planting date of wheat. Under conditions of below normal rainfall, the response of winter wheat yields to planting dates ranged from 20.24 bu/ac to 23.79 bu/ac. For Ochiltree County, planting dates had an inconsistent effect on the yields of dryland winter wheat at below normal rainfall conditions. Both early and late plantings were

Table 1. Effects of Plant Population under Below Normal Rainfall Scenario, Ochiltree County

Population (plants/ac)	Yield (bu)	Gross returns ($/ac)	Variable cost ($/ac)	Profits ($/ac)	Avg. Net Return ranking	SDRF ranking
300,694	17.71	53.21	48.99	4.22	16	16
310,694	18.05	54.24	49.04	5.20	15	15
320,694	18.39	55.26	49.09	6.17	14	14
330,694	18.73	56.28	49.14	7.14	13	13
340,694	19.06	57.27	49.19	8.08	12	11
350,694	19.40	58.29	49.24	9.05	11	10
360,694	19.57	58.80	49.29	9.51	10	12
370,694	19.91	59.82	49.34	10.48	9	8
380,694	20.08	60.34	49.39	10.95	8	9
390,694	20.24	60.82	49.44	11.38	7	7
400,694	20.41	61.33	49.49	11.84	6	6
410,694	20.58	61.84	49.54	12.30	5	5
420,694	20.75	62.35	49.59	12.76	4	4
430,694	20.92	62.86	49.64	13.22	3	1
440,694	21.09	63.37	49.69	13.68	2	2
450,694	21.26	63.88	49.74	14.14	1	3

Table 2. Effects of Plant Population under Above Normal Rainfall Scenario, Ochiltree County

Population (plants/ac)	Yield (bu)	Gross returns ($/ac)	Variable cost ($/ac)	Profits ($/ac)	Avg. Net Return ranking	SDRF ranking
300,694	25.47	76.53	48.99	27.54	16	14
310,694	25.98	78.06	49.04	29.02	15	15
320,694	26.32	79.09	49.09	30.00	14	16
330,694	26.82	80.59	49.14	31.45	13	13
340,694	27.16	81.61	49.19	32.42	12	12
350,694	27.50	82.63	49.24	33.39	11	10
360,694	27.84	83.65	49.29	34.36	10	11
370,694	28.17	84.65	49.34	35.31	9	9
380,694	28.51	85.67	49.39	36.28	8	7
390,694	28.68	86.18	49.44	36.74	7	8
400,694	28.85	86.69	49.49	37.20	6	6
410,694	29.19	87.71	49.54	38.17	5	4
420,694	29.35	88.19	49.59	38.60	4	5
430,694	29.52	88.70	49.64	39.06	3	3
440,694	29.69	89.21	49.69	39.52	2	2
450,694	29.86	89.72	49.74	39.98	1	1

found to be favorable for higher returns (Table 3). In case of high rainfall conditions, only early plantings had a clear advantage over other planting dates (Table 4).

Wheat responded positively to rainfall with yields in good rainfall situations ranging from 28.51 to 33.40 bu/ac. The present analysis showed that early planting is advisable, if the rainfall forecast for the next season is considered to be above normal. Early planting with enough precipitation helps seeds to germinate and plants to grow properly, resulting in higher economic returns. If sowing is delayed under good rainfall conditions, yields would be reduced significantly, by up to 29% in Ochiltree County. The delayed sowing exposes the wheat plant to water stress in the grain filling period, causing a reduction in yields. The other possible cause for the reduction in yields could be due to delayed sowing which enhances the susceptibility of the wheat to possible attack by rust and other diseases due to water limiting conditions.

Table 3. Planting Date Influences under Below Normal Rainfall Scenario, Ochiltree County

Planting date (dd/mm)	Yield (bu)	Gross returns ($/ac)	Variable cost ($/ac)	Profits ($/ac)	Avg. Net Return ranking	SDRF ranking
01/09	23.79	71.48	49.49	21.99	1	1
07/09	21.26	63.88	49.49	14.39	3	2
14/09	20.75	62.35	49.49	12.86	5	5
21/09	20.75	62.35	49.49	12.86	5	8
26/09	20.58	61.84	49.49	12.35	6	9
01/10	20.24	60.82	49.49	11.33	7	10
07/10	20.92	62.86	49.49	13.37	4	7
14/10	21.26	63.88	49.49	14.39	3	6
21/10	21.42	64.36	49.49	14.87	2	3
28/10	21.42	64.36	49.49	14.87	2	4

Table 4. Planting Date Influences under Above Normal Rainfall Scenario, Ochiltree County

Planting date (dd/mm)	Yield (bu)	Gross returns ($/ac)	Variable cost ($/ac)	Profits ($/ac)	Avg. Net Return ranking	SDRF ranking
01/09	33.40	100.36	49.49	50.87	1	1
07/09	29.86	89.72	49.49	40.23	2	2
14/09	29.19	87.71	49.49	38.22	3	3
21/09	29.02	87.20	49.49	37.71	4	5
26/09	29.02	87.20	49.49	37.71	4	4
01/10	28.85	86.69	49.49	37.20	5	6
07/10	28.85	86.69	49.49	37.20	5	7
14/10	28.85	86.69	49.49	37.20	5	8
21/10	28.51	85.67	49.49	36.18	6	10
28/10	28.51	85.67	49.49	36.18	6	9

This study found that fertility effects had a substantial influence on the yields of winter wheat. Twenty pounds of elemental N or 100 lb of 22-08-02 blend or 125 lbs of 18-08-04 fertilizer resulted in higher returns for Ochiltree County under below normal rainfall conditions (Table 5) whereas SDRF results indicated that the dominant practice would be 125 lbs of 18-08-04. Higher fertilizer rates were found to be necessary for higher returns under above normal rainfall conditions. Thus, 40 lbs of elemental N or 200 lbs of 22-08-02 or 250 lbs of 18-08-04 fertilizer would be required for a nutrient stress free plant growth (Table 6).

Best Combination of Management Practices

The top three risk efficient management practices with respect to planting density, planting date and fertilization were combined with other practices and the yield levels were simulated using CroPMan to evaluate the economic benefits of seasonal rainfall information. Winter wheat best management practices for Ochiltree County under below normal rainfall conditions are presented in Table 7. The results indicate that initiating planting on 1st September with a population density of 450,694 plants/ac and using 100 lbs of 22-08-02 fertilizer resulted in highest profits of $26.72 with an estimated yield of 24.12 bu/ac. If planting is further delayed by a week due to unanticipated weather conditions, then the next recommended planting strategy would be planting 7th September with a plant population of 450,694 plants/ac and using 100 lbs of 22-08-02. Under below normal rainfall conditions, results from the best combination of management practices reveal that Ochiltree County's dryland winter wheat producers would increase their profits up to $14.47/ac, as against no modification of management practices.

If above normal rainfall conditions prevail in the coming season at Ochiltree County, it would be advisable for dryland farmers to initiate planting on 1st September with a planting density of 450,694 plants/ac and using 250 lbs of 18-08-04 fertilizer (Table 8). The expected profits from the above combination practices were found to be $48.20/ac. The profits for Ochiltree winter wheat production showed that modifying management practices based on seasonal rainfall expectation would increase the revenues up to $10.63/ac.

Approximately about 1.6 million acres of dryland winter wheat was planted in the Texas High Plains in 2003. The potential value of seasonal climate information for changing winter wheat management practices (planting date, fertilizer amount, and planting density) is found to be from $18 to $32 million per year for Texas High Plains region. Thus, results from winter wheat reveal that tailoring management practices based on seasonal rainfall expectations is a viable option for managing climate risk and increasing mean income for High Plains dryland farmers.

CONCLUSIONS

Any research which directed towards decreasing the variability in returns in dryland production due to climatic uncertainty would benefit the producers. This analysis has quantified the effects of planting dates, planting densities and fertilization amounts on winter wheat yield under below and above normal rainfall scenarios in the Texas High Plains. Simulated results showed potential benefits of $18 to $32 million per year if management decisions were based on expected seasonal rainfall information. As like in any other study, some limiting assumptions were made in order to achieve the objectives of this study. Results presented in this investigation are by no means the definitive answers, but provide useful guidelines for farmers about the value of climate information and the necessity to adjust management practices based on such information.

Table 5. Impacts of Fertilization under Below Normal Rainfall Scenario, Ochiltree County

Fertilizer (lb/ac)	Yield (bu)	N stress (days)	Gross returns ($/ac)	Variable cost ($/ac)	Profits ($/ac)	Avg. Net Return ranking	SDRF ranking
Elemental N							
20	20.08	1.4	60.34	47.15	13.19	7	7
30	20.58	0	61.84	49.49	12.35	8	8
40	20.58	0	61.84	51.83	10.01	9	9
22-08-02							
75	19.06	4.4	57.27	44.04	13.22	6	6
100	20.41	0.6	61.33	45.39	15.93	1	2
125	20.58	0	61.84	46.74	15.10	3	4
18-08-04							
100	19.57	3	58.80	44.50	14.30	5	5
125	20.41	0.5	61.33	45.62	15.70	2	1
150	20.58	0	61.84	46.75	15.08	4	3

Table 6. Impacts of Fertilization under Above Normal Rainfall Scenario, Ochiltree County

Fertilizer (lb/ac)	Yield (bu)	N stress (days)	Gross returns ($/ac)	Variable cost ($/ac)	Profits ($/ac)	Avg. Net Return ranking	SDRF ranking
Elemental N							
30	25.14	8.2	75.54	49.49	26.05	9	9
40	28.51	1.2	85.67	51.83	33.84	6	7
50	29.02	0	87.20	54.17	33.03	8	8
22-08-02							
175	28.17	1.7	84.65	49.43	35.21	4	5
200	28.85	0.3	86.69	50.78	35.91	2	2
225	29.02	0	87.20	52.12	35.07	5	4
18-08-04							
200	27.50	3.3	82.63	49.00	33.63	7	6
225	28.51	1.0	85.67	50.12	35.54	3	3
250	29.02	0.2	87.20	51.24	35.95	1	1

Table 7. Economic Benefits of Best Management Practices under Below Normal Rainfall Conditions, Ochiltree County

Population (Plants/ac)	Planting Date	Fertilization (lbs/ac)	Yield (bu/ac)	Gross Returns ($/ac)	Variable Cost ($/ac)	Profit ($/ac)
430,694	09/01	125+	23.96	71.88	45.77	26.11
430,694	09/07	125+	21.59	64.77	45.77	19.00
430,694	10/21	125+	21.42	64.26	45.77	18.49
430,694	09/01	150+	23.96	71.88	46.90	24.98
430,694	09/07	150+	21.59	64.77	46.90	17.87
430,694	10/21	150+	21.42	64.26	46.90	17.36
430,694	09/01	100*	23.96	71.88	45.54	26.34
430,694	09/07	100*	21.59	64.77	45.54	19.23
430,694	10/21	100*	21.42	64.26	45.54	18.72
440,694	09/01	125+	23.96	71.88	45.82	26.06
440,694	09/07	125+	21.59	64.77	45.82	18.95
440,694	10/21	125+	21.59	64.77	45.82	18.95
440,694	09/01	150+	23.96	71.88	46.85	25.03
440,694	09/07	150+	21.59	64.77	46.85	17.92
440,694	10/21	150+	21.59	64.77	46.85	17.92
440,694	09/01	100*	23.96	71.88	45.59	26.29
440,694	09/07	100*	21.59	64.77	45.59	19.18
440,694	10/21	100*	21.59	64.77	45.59	19.18
450,694	09/01	125+	24.12	72.36	45.87	26.49
450,694	09/07	125+	21.76	65.28	45.87	19.41
450,694	10/21	125+	21.76	65.28	45.87	19.41
450,694	09/01	150+	24.12	72.36	47.00	25.36
450,694	09/07	150+	21.76	65.28	47.00	18.28
450,694	10/21	150+	21.76	65.28	47.00	18.28
450,694	09/01	100*	24.12	72.36	45.64	26.72
450,694	09/07	100*	21.76	65.28	45.64	19.64
450,694	10/21	100*	21.76	65.28	45.64	19.64

Note: + indicate 18-08-04 fertilizer combination, * represent 22-08-02 fertilizer combination

Table 8. Economic Benefits of Best Management Practices under Above Normal Rainfall Conditions, Ochiltree County

Population (Plants/ac)	Planting Date	Fertilization (lbs/ac)	Yield (bu/ac)	Gross Returns ($/ac)	Variable Cost ($/ac)	Profit ($/ac)
430,694	09/01	225+	31.72	95.16	50.27	44.89
430,694	09/07	225+	29.35	88.05	50.27	37.78
430,694	09/14	225+	28.68	86.04	50.27	35.77
430,694	09/01	250+	33.07	99.21	51.39	47.82
430,694	09/07	250+	30.03	90.09	51.39	38.70
430,694	09/14	250+	29.52	88.56	51.39	37.17
430,694	09/01	200*	32.73	98.19	50.93	47.26
430,694	09/07	200*	30.03	90.09	50.93	39.16
430,694	09/14	200*	29.35	88.05	50.93	37.12
440,694	09/01	225+	31.72	95.16	50.32	44.84
440,694	09/07	225+	29.35	88.05	50.32	37.73
440,694	09/14	225+	28.68	86.04	50.32	35.72
440,694	09/01	250+	33.07	99.21	51.44	47.77
440,694	09/07	250+	30.20	90.60	51.44	39.16
440,694	09/14	250+	29.52	88.56	51.44	37.12
440,694	09/01	200*	32.90	98.70	50.98	47.72
440,694	09/07	200*	30.03	90.09	50.98	39.11
440,694	09/14	200*	29.35	88.05	50.98	37.07
450,694	09/01	225+	31.72	95.16	50.37	44.79
450,694	09/07	225+	29.52	88.56	50.37	38.19
450,694	09/14	225+	28.51	85.53	50.37	35.16
450,694	09/01	250+	33.23	99.69	51.49	48.20
450,694	09/07	250+	30.37	91.11	51.49	39.62
450,694	09/14	250+	29.69	89.07	51.49	37.58
450,694	09/01	200*	32.90	98.70	51.03	47.67
450,694	09/07	200*	30.20	90.60	51.03	39.57
450,694	09/14	200*	29.52	88.56	51.03	37.53

Note: + indicate 18-08-04 fertilizer combination, * represent 22-08-02 fertilizer combination

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