Climatic Risk to Cotton Production in the Ogallala Aquifer Region

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ABSTRACT

Renewed interest in cotton (*Gossypium hirsutum* L.) production in the Ogallala aquifer region can be tied to increased profitability associated with the growing demand for cotton, development of short-season varieties, rising energy costs, and declining water levels in the Ogallala Aquifer. However, the feasibility of growing cotton considering climatic characteristics of the region has not been determined. In this study, we used a county-wise daily maximum and minimum air temperature database to assess climatic suitability for farming cotton in the Ogallala aquifer region. For this purpose, a 30-year (1971-2000) climatic dataset was obtained from the National Climatic Data Center. Exceedance probability curves for total heat units accumulated during growing season were developed and used to identify those counties that are suitable for farming cotton at different exceedance probability levels. Results indicate that counties in the southern high plains region provide suitable climatic conditions to grow cotton as expected. However, counties in the central high plains that include the Texas and Oklahoma panhandles and southern Kansas require varieties adopted for cooler and shorter growing seasons. Out of 131 counties, 102 counties receive 1800 or more heat units during the planting season at least once every two years. Significant water savings is possible if producers were to switch 50 percent of their irrigated corn acreage to cotton. Furthermore, information derived from this study is of interest to producers and commodity groups, seed developers, crop insurance companies and water resource management agencies.

INTRODUCTION

Cotton (*Gossypium hirsutum L.*) is the most important textile fiber in the world, accounting for more than 40 percent of the total world fiber production. It is grown in more than 100 countries with the United States ranking second behind China (ERS, 2005). The annual revenue generated by cotton and its products in the U.S. accounts for about $40 billion. Cotton has largely been located south of 37 deg N latitude in what is called the cotton belt in the United States. However, in recent years, cotton production is expanding to include the northern part of the Texas high plains, Oklahoma, and parts of Kansas where corn has traditionally been produced (Colaizzi et al., 2004). This expansion in production can be associated with the growing demand for cotton, development of short-season varieties (Duncan et al., 1993), warmer climatic conditions and declining water levels in the Ogallala aquifer (Wheeler et al., 2004).

The Ogallala aquifer covers about 450,650 km^2 and has an average depth of 61 m with a maximum of about 305 m. The largest portion of the aquifer underlies the High Plains of Texas, Kansas, Nebraska, New Mexico, Colorado, and Oklahoma. Use of groundwater from the Ogallala aquifer began at the beginning of the twentieth century and increased steadily after World War II. Roughly 90 percent of the water pumped from the Ogallala aquifer is being used to irrigate one fifth of all U.S. cropland and this water accounts for about 30% of all groundwater used for irrigation in the United States. Crops grown in this area include alfalfa, corn, cotton, sorghum, soybeans and wheat.

The Ogallala aquifer is experiencing declining water levels, which encourages water conservation in this region. One of the options to conserve water and possibly extend the life of the Ogallala aquifer is to look for drought resistant, economically viable, alternative crops. Cotton is a perennial tree that has been cultured as an annual crop. It requires less water (500 mm) than other major crops grown in the region, such as corn (835 mm), sorghum (577 mm) and soybean (681 mm) (New and Dusek, 2005), and provides equivalent or higher economic gains per acre than corn to producers. Moreover, in recent years, there is a renewed interest among producers to grow cotton in the southern and central high plains of the Ogallala aquifer region due to profitability issues.

Cotton development is mainly dependent on temperature during early growth. Cool temperatures early in the season can slow growth at emergence and delay fruit initiation. Water use from emergence to first bloom increases from less than 25 to 50 mm per week, and early season water stress should be avoided. From first bloom to the first open boll, weather conditions and water supply can greatly influence plant development. Fiber initiation is sensitive to high temperatures and will lead to shorter fibers, smaller seeds, fewer seeds per boll, and smaller bolls. Warm weather can increase micronaire values, while water use can increase to as much as 70 mm per week. The final growth stage reflects the weather and management practices that have taken place throughout the season (Sansone et al., 2002).

After crop water requirements, the most important factor in the development of cotton is temperature. Temperature is the limiting factor in temperate climates, but the northern limits of latitude for cotton production are being pushed by short season varieties. Temperature determines the length of the growing season and has a strong relationship with the potential yield of cotton (Waddle, 1984). Cotton requires sunlight and high temperatures for optimum growth with an optimum temperature of 90 deg F (Munro, 1987). Cotton needs more than 160 days with temperatures greater than 60 deg F and generally becomes inactive at temperatures less than 60 degree F.

A heat unit (HU) is a measure of the amount of heat energy a plant accumulates each day during the growing season, and is calculated from daily maximum and minimum air temperature values as:

$$HU = (\text{Deg. F maximum} + \text{Deg. F minimum}) / 2 - 60 \quad \text{when } HU > 0.0 \qquad [1]$$

Cotton requires about 2,600 heat units (^{0}F) from planting to harvest to mature a crop (Waddle, 1984).

Planting date has an impact on crop growth, development, and yield. Early planting is important as it helps growers to avoid inclement weather and late-season pests (Silvertooth and Norton, 1999). Planting date is also important to determine the length of the growing season, the number of cultivations and trips across a field to salvage a stand. To reduce damage, a uniform planting date of May 15 or later is suggested for the high plains region. For insurance purposes, cotton can not be planted before May 10. The last practical date for planting is June 20 (Warrick et al., 2002). Planting after May 15 helps seedling emergence and allows for faster stand development due to higher soil temperatures.

Overall, considering the less water requirements and availability of short season varieties, increased energy prices, and depleting groundwater levels, it is believed that cotton is a viable alternative crop to corn in southern and central high plains region. However, there has been no formal study conducted to document available total heat units between planting and harvesting dates for cotton, and their frequency to determine feasibility to grow cotton in the Ogallala aquifer region. The main objectives of this study are: (1) to develop a county-wise daily minimum and maximum air temperature database; (2) to assess suitability of climatic conditions for farming cotton based on the heat units concept; and (3) to assess the potential water savings by growing cotton as an alternative to corn in the Ogallala aquifer region.

STUDY AREA

This study focuses on the Ogallala aquifer region below 40 deg N Latitude including parts of Kansas, Oklahoma, Colorado, New Mexico, and Texas (Figure 1). There are about 131 counties in this region with a total area of about 413,201 km^2. This region includes arid, semi-arid, and sub-humid environments (McGuire et al., 2003). Precipitation ranges from 366 mm in the western part to about 813 mm in the east. The major irrigated crops in the study area include corn, winter wheat, cotton, sorghum, soybean, and peanuts. The major geological unit in the region is the Ogallala formation consisting of poorly sorted clay, silt, sand, and gravel, generally unconsolidated, and is the source of groundwater for irrigation to supplement generally the inadequate rainfall for agricultural production.

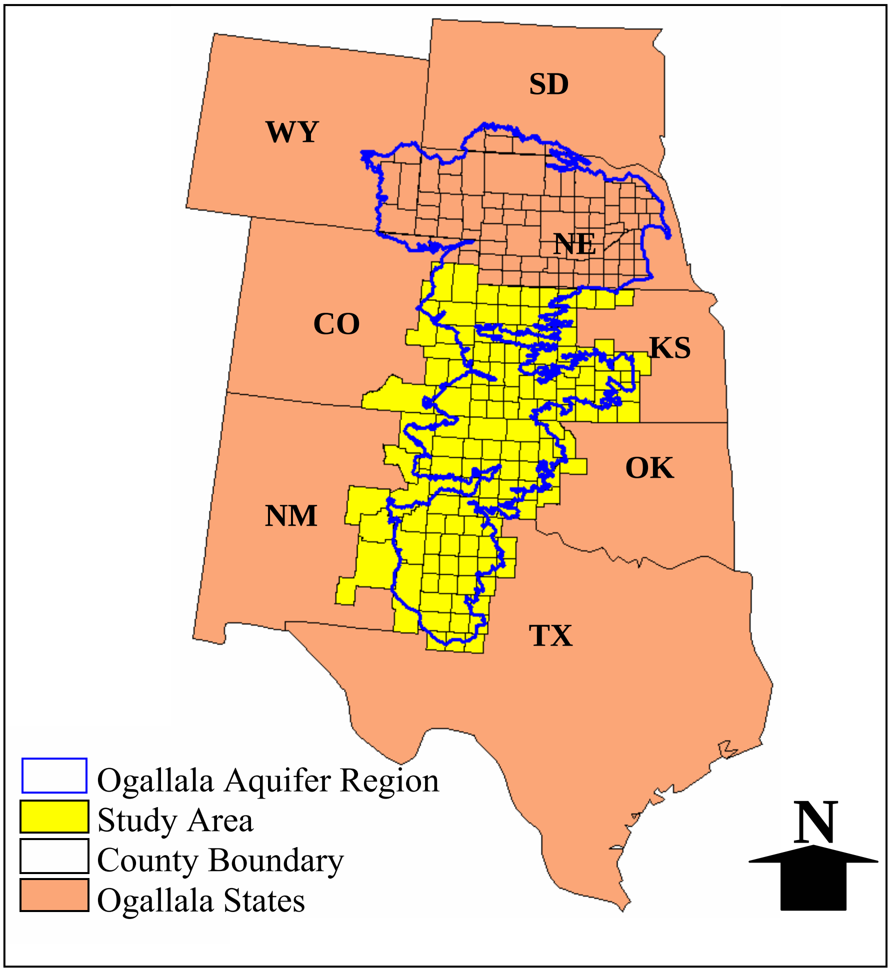

Figure 1. Location of the study area in the central U.S.

MATERIALS AND METHODS

A long-term climatic data set was obtained from the National Climatic Data Center for the high plain states in the central U.S. The data set consists of maximum and minimum air temperature data from all weather stations maintained by the National Weather Service (NWS) as well as weather stations maintained by cooperating agencies. Based on the period, availability and continuity of daily observations, a set of weather stations were selected for all counties within the study area. Daily values of maximum and minimum air temperatures were taken from one station in each county that contained the most complete data for the years 1971 to

2000. Missing values were supplemented with data from neighboring stations within the same county. For counties with no weather stations, average daily values of maximum and minimum air temperature were calculated using the data from surrounding counties. For each county, we calculated heat units accumulated for each year between planting and harvesting dates for cotton using Eq.1. A computer program was written to automate the heat unit calculations for 131 counties in the study area. Three different planting dates: May 15, June 1, and June 15 and a harvest date of October 31, were used to calculate heat units.

Climatic variability from year to year impact cotton yield as it affects total plant available heat energy during the growing season. Better understanding of climatic variability is important for producers and crop insurance companies to cope up with associated risks. For producers, it helps to set realistic yield goals and plan appropriate management practices. For crop insurance companies, it provides a scientific basis to calculate insurance premiums based on geographic location and yield goals. Therefore, the calculated heat units were ranked in decreasing order and the exceedance probability (P) was calculated as:

$$P = \frac{N}{(n+1)} \qquad [2]$$

where N is the rank of the annual estimated value and n is the total number of years (Haan et al., 1994). The exceedance probability for an event of a given magnitude is defined as the probability that an event of equal or greater magnitude will occur in any single year. It can also be calculated as the inverse of the return period. For example, a rainfall event with an exceedance probability of 0.5 will occur at least once in 2 years.

To understand the spatial pattern of calculated annual heat units for different sets of planting and harvesting dates over the study area, a set of maps were made using a Geographic Information System. It includes a county-wise 30-year average heat unit map and heat unit maps for exceedance probability of 0.1 (10-yr return period), 0.2 (5-yr return period) and 0.5 (2-yr return period). Finally, a county-wise estimate of potential water saving was made by replacing 50 percent of the total corn acreage with cotton in counties that accumulate 1800 or more heat units at least once every two years (2-yr return period).

RESULTS AND DISCUSSIONS

Based on long-term (1971-2000) air temperature records for the study area, a set of maps showing county-wise annual heat unit accumulation with different planting dates was made to determine counties that are thermally suitable for growing cotton.

Figures 2(a-c) illustrate the 30-yr average annual heat units calculated with planting dates of May 15, June 1 and June 15. The average annual heat units for the study area was about 2054 with a planting date of May 15, 1920 with a planting date of June 1, and 1756 with a planting date of June 15. Ector County, TX and Union County, CO recorded the maximum and minimum heat units, respectively, for all three planting dates. As expected, the heat units were higher for the earlier planting date (May 15th) than for the later planting dates (June 1st and 15th). For example, annual total heat units for Ector County varied from 2843 with a planting date of May 15 to 2581 for June 1 to 2325 for June 15. There is about a 9 percent reduction in the accumulation of heat units for every 15 days delay in planting cotton. However, this varied from one county to another. County-wise analysis of heat units indicated that there are only 10 counties (9 in Texas Panhandle and one in Oklahoma) that exceed or meet the 2600 heat unit requirement to mature a crop. Due to availability of short-term cotton varieties in recent years, farmers in the Texas Panhandle have shown that economically viable cotton can be grown with about 1800 heat units (Pers. Comm. with Thomas Marek, Texas Agricultural Experiment Station). With a planting date of May 15, there were 104 counties (44 in Texas, 45 in Kansas, 6 in New Mexico, 9 in Oklahoma) that received a minimum of 1800 heat units (Figure 2a). However, there were only 88 counties that received 1800 or more heat units when the planting date was delayed to June 1st, and 59 counties with June 15 planting date. Most of the counties that received less than 1800 units with later planting dates are located in Kansas (see Figures 2b&c). This indicates planting date is one of the key factors in deciding whether to grow cotton in a given county. In other words, cotton varieties which cold resistant and allow early planting are required to grow cotton in those counties.

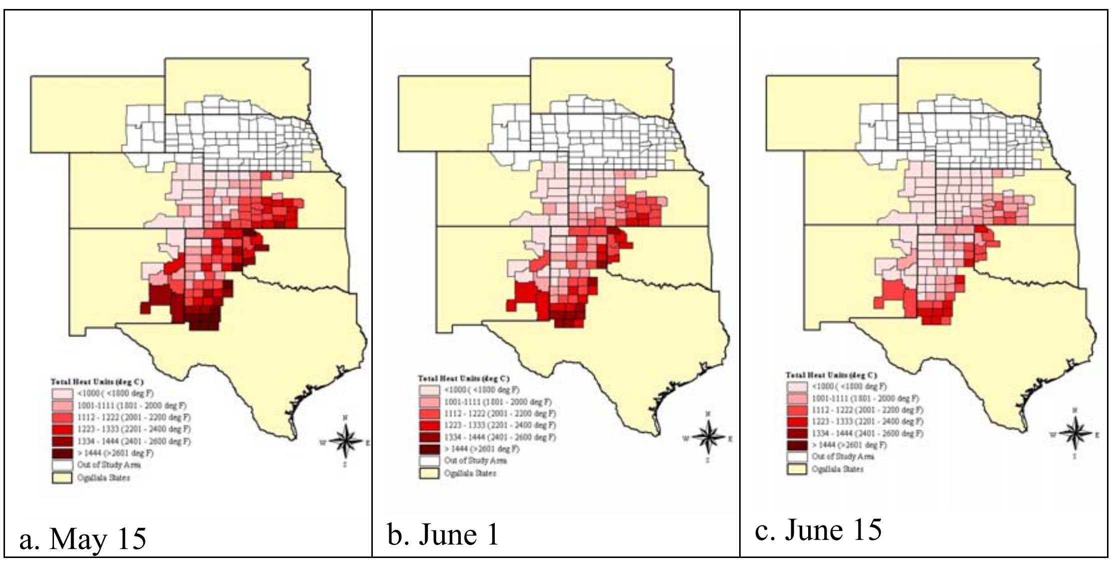

Figure 2. County-wise 30-year mean accumulated heat units for three planting dates.

Figure 3(a-i) illustrates county-wise annual accumulated heat units for cotton at three planting dates with 2, 5 and 10-year return periods. Counties located in the south and southeastern parts of the region receive more heat units and are more suitable for growing cotton. Table 1 presents the total number of counties that are suitable for growing cotton at three planting dates with three return periods. As expected, the number of counties that receive enough critical heat units to grow cotton increased with an increase in the return period. For example, with the May 15 planting date, the total number of counties that receive a minimum of 1800 heat units increased from 102 to 120 when the return period was increased from 2 to 10 years. With a 2-year return period, 9 counties received more than 2600 heat units and 38 counties received a minimum of 2200 heat units. Most counties (102 out of 131) received more than 1800 heat units indicating that short-term and cold resistant cotton varieties are needed to increase the cotton acreage in the Ogallala aquifer region.

Table 1. Total number of counties suitable for growing cotton with combinations of three planting dates and three return periods.[1]

Critical Heat Units	Planting Date								
	RP with May 15			RP with June 1			RP with June 15		
	2 yr P=0.5	5 yr P=0.2	10 yr P=0.1	2 yr P=0.5	5 yr P=0.2	10 yr P=0.1	2 yr P=0.5	5 yr P=0.2	10 yr P=0.1
$\geq$ 1800	102	116	120	91	112	116	63	90	109
$\geq$ 2200	38	71	93	21	54	67	8	26	42
$\geq$ 2600	9	22	37	-	9	17	-	-	4

[1]RP – Return period, P – Exceedance probability

Figure 4 illustrates the county-wise potential water savings if producers were to switch about 50 percent of their total irrigated corn acreage to cotton in counties that receive at least 1800 heat units when cotton is planted on May 15 or before. This converts approximately 325,000 ha presently under irrigated corn (NASS, 2004) to cotton, and provides a potential annual water savings of about 1.11 billion m^3 in the 131-county study area.

CONCLUSIONS

The Ogallala aquifer provides about 30 percent of all groundwater used for irrigation in the U.S. The aquifer is facing declining water levels and is projected to deplete in about 50 years if the current usage level continues. One of the options to optimize the use of limited water is to look for drought-resistant and economically viable alternative crops. In this study, feasibility for growing cotton in the Ogallala aquifer region was evaluated based on availability of heat units during the cropping season

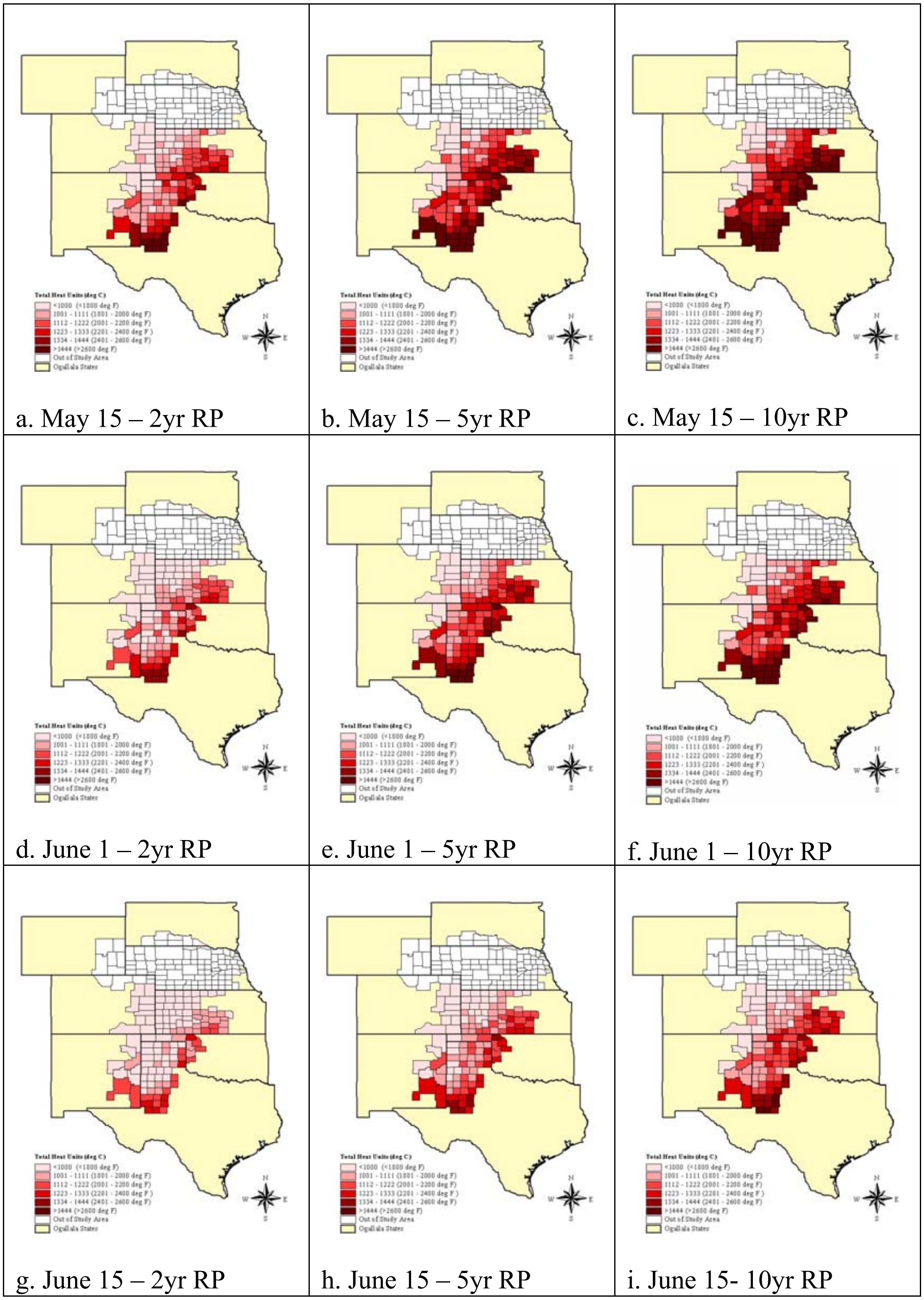

Figure 3. County-wise annual accumulated heat units for three different planting dates with 2, 5 and 10-year return periods (RP – Return Period).

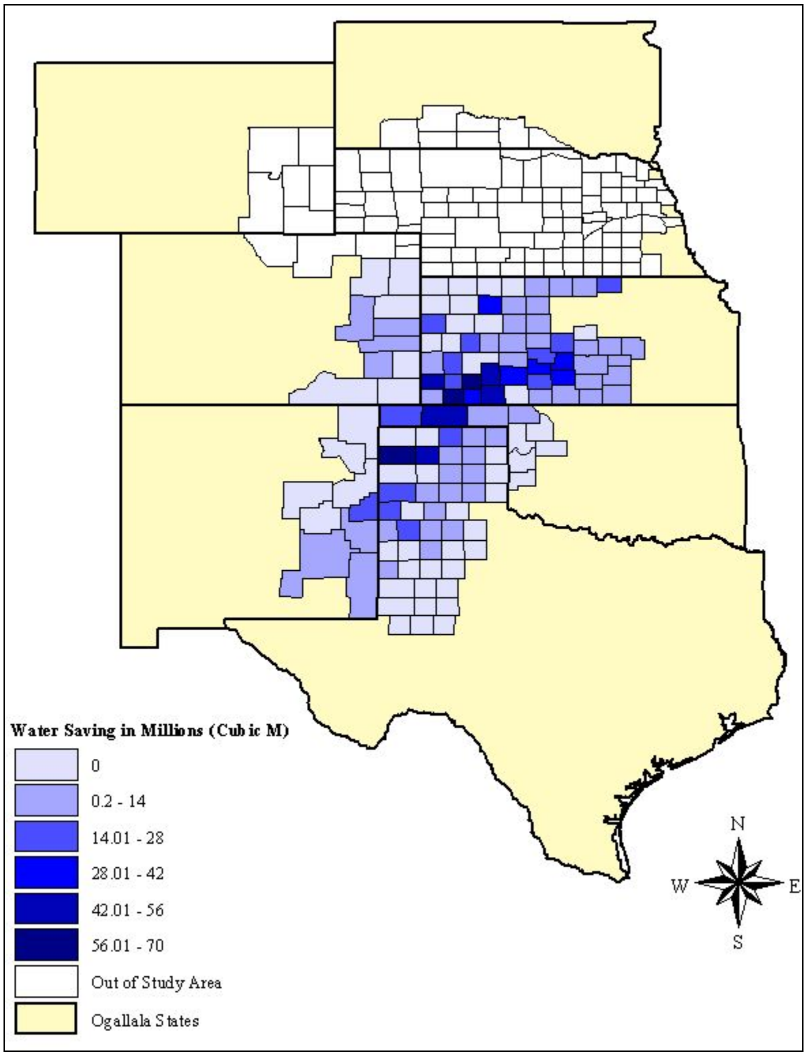

Figure 4. County-wise potential annual water savings when about 50 percent of the irrigated corn acreage is switched to cotton.

using a 30-year county-wise maximum and minimum air temperature database. County-wise heat unit estimates were made with three planting dates selected within the insurance cutoff-period, and exceedance probability curves were developed. Results indicate that counties in the southern high plains provide suitable climatic conditions to grow cotton as expected. However, counties in the central high plains that include the Texas and Oklahoma panhandles and southern Kansas require short season varieties that allow early planting. Significant water savings is possible if producers were to switch 50 percent of their corn acreage to cotton. Information derived from this study is of interest to producers and commodity groups, seed developers, crop insurance companies and water resources management agencies.

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