EVALUATING COTTON YIELD POTENTIAL IN THE OGALLALA AQUIFER REGION

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ABSTRACT

Renewed interest in cotton production in the Ogallala aquifer region can be tied to development of early maturing varieties, and declining water levels in the Ogallala aquifer. However, the feasibility of growing cotton considering thermal characteristics of the region has not been determined. In this study, the heat unit based county-wide exceedance probability curves for potential cotton yield were developed using a long term temperature dataset (1971-2000) and identified counties that have the potential to grow cotton at 1- and 2-year return periods. Out of 131 counties in the study area, 105 counties have the potential to grow cotton with lint yield more than 500 kg/ha. Evaluation of county-wide potential cotton yield indicate that yield goals based on a 2-year return period may improve the chances of better profits to producers than yield goals with 1-year return period. However, management uncertainties on irrigation efficiencies, fertilizer and pest management, planting and harvesting schedule may require further consideration for estimating potential cotton yield. Nevertheless, these results show that cotton is a suitable alternative crop for most counties in southwest Kansas and all counties in Texas and Oklahoma Panhandles. Also, a significant reduction in annual water withdrawals (about 60.4 million ha-mm) from the Ogallala aquifer for irrigation is possible if producers were to switch 50 percent of their corn acreage to cotton in counties that have yield potential more than 500 kg/ha.

INTRODUCTION

In recent years, cotton (*Gossypium hirsutum* L.) production is slowly expanding to include Central High Plains of the Ogallala aquifer region that includes Texas

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and Oklahoma Panhandles and southwestern counties in Kansas where corn has traditionally been produced (Colaizzi et al., 2004). This renewed interest in cotton production can be associated with the development of early maturing varieties, increasing energy prices, and declining water levels in the Ogallala aquifer (Wheeler et al., 2004). One of the options to potentially reduce the use of groundwater and possibly extend the life of the Ogallala aquifer is to look for drought tolerant, economically viable, alternative crops. Cotton is a perennial tree that has been cultured as an annual crop. Crop water use statistics for Texas High Plains indicate that cotton requires less water (647 mm) than other major crops grown in the region, such as corn (835 mm), sorghum (688 mm) and soybean (681 mm) (Leon and Dusek, 2005). However, temperature, the second most important factor in the development of cotton after water, is a limiting factor in the Central and Northern High Plains of the Ogallala aquifer region. It determines the length of the growing season and has a strong relation with cotton yield (Waddle, 1984).

Cotton needs sunlight and high temperatures for optimum growth with an optimum temperature of 32.2 ^{o}C (Munro, 1987). The amount of heat energy a plant accumulates is usually presented in heat units or growing degree days. 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:

$$HU = ({}^{o}C \text{ maximum} + {}^{o}C \text{ minimum}) / 2 - T_t \, {}^{o}C \qquad \text{when } HU > 0.0 \qquad [1]$$

This concept of heat units resulted from observations that plants do not grow below a threshold temperature (T_t). The T_t for cotton plant is 15.6 ^{o}C. Crop growth and development of cotton are directly related to accumulated heat units when other environmental factors are not limiting (Peng et al., 1989).

Table 1 presents phenological heat unit requirements for cotton from planting to maturity in the southern Texas High Plains. Cotton requires about 1444 heat units (^{o}C) from planting to harvest to mature a crop (Table 1) (Waddle, 1984). However, in recent years, farmers in the Texas Panhandle have shown that economically viable cotton can be grown with about 1000 heat units (Howell et al., 2004). With 1000 heat units, cotton plant can produce one open boll and 4 more bolls are 85% matured (Wrona et al., 1996). Crop termination through defoliation at this stage of plant development results in a yield loss about 1% of total yield but does not reduce the fiber quality (Wrona et al., 1996).

Table 1. Phenological heat unit requirements for development of cotton crop to maturity in the southern Texas High Plains.

Stage of Development	Plant Age (Days)	Accumulated Heat Units (Base Temp=15.6 ^{o}C)
Germination-Seedling Establishment	5-15	44-55
Square Initiation	35-50	250-306
First Flower	55-70	528-556
Peak Flower	75-95	506-861
First Open Boll	100-120	1000-1056
50% Open Boll	120-140	1194-1250
80% Maturity	140-170	1278-1361
100% Maturity	150-180	1389-1444

Source: D.R. Krieg, personal communication, 17 Feb. 2006.

Timing of planting and harvesting of cotton 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). Generally, cotton is planted when soil temperature reaches 15.6 ^{o}C or more. Emergence, stand and vigor are adversely affected when soil temperatures fall below 15.6 ^{o}C. If planted too early when soils are cooler than 12.8 ^{o}C, a cotton crop may suffer stand loss, seedling disease problems and cold temperature stress, which reduce yield (Sansone et al., 2002). Soil temperature at planting depth is influenced by air temperature due to the proximity of the seed zone to the atmosphere and the thin layer of seed zone soil (Brown, 2000). He demonstrated a linear relation between soil and minimum and maximum air temperature data from the Arizona Meteorological Network (AZMET). Esparza et al. (2006) developed a set of linear regression relationships to estimate daily minimum soil temperature from daily maximum and minimum air temperature in the Ogallala aquifer region. Selection of harvesting date for cotton depends upon first day of freezing in the fall, cotton variety, fall rainfall forecast and/or yield goal.

OBJECTIVES

Due to lower water requirements, availability of early maturing varieties, highly fluctuating energy prices, and depleting groundwater levels, it is believed that cotton is a viable alternative crop to corn in the Southern and Central High Plains of the Ogallala aquifer region. However, there has been no formal study conducted to document the availability and frequency of total heat units during the cropping season and the cotton yield potential in order to determine the physical and financial feasibility of growing cotton. Therefore, the main objectives of this study were to assess (1) thermal feasibility of growing cotton and estimate cotton yield potential; and (2) the potential reduction in Ogallala water withdrawals by growing cotton as an alternative to corn in the region.

MATERIALS AND METHODS

Study Area

This study focuses on the Ogallala aquifer region below 40^{o} N Latitude including all of Southern and Central High Plains and a part of Northern High Plains (Figure 1). There are 131 counties in this region with a total area of about 413,200 km^2. This region is described as being between a semiarid to arid environment in the south and a moist sub-humid environment in the north (McGuire et al., 2003). Annual precipitation in the area 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. Although the Southern High Plains are known for cotton production, it was included in the study to estimate potential cotton yield.

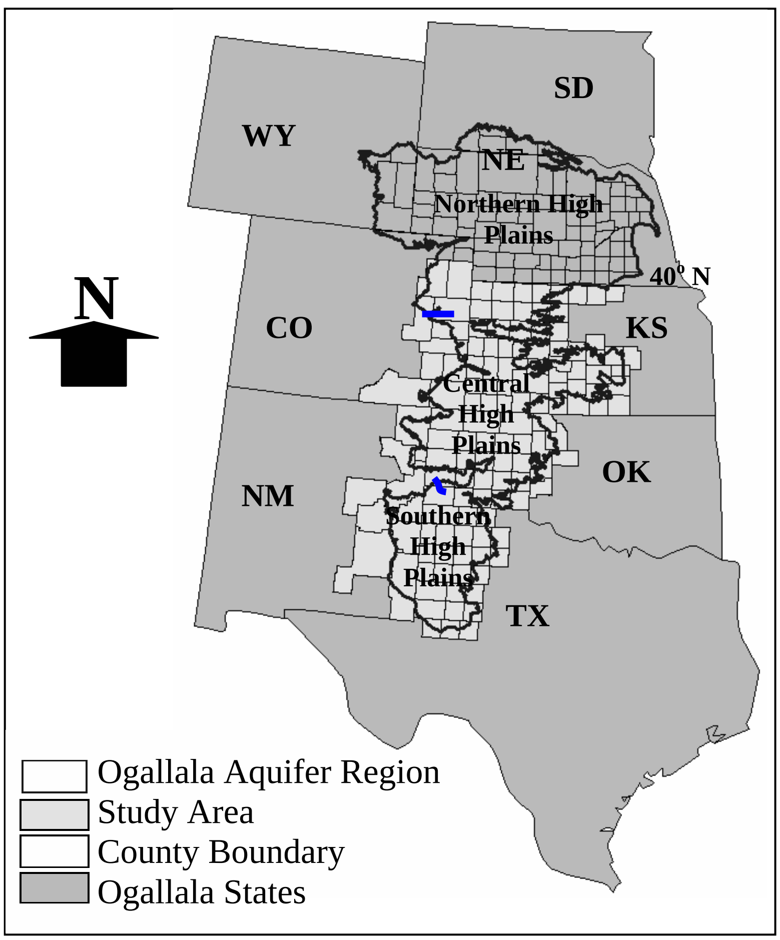

Figure 1. Location of the study area in the central U.S.

Database Development

A long-term climatic data set from the National Climatic Data Center for counties in the Ogallala aquifer region was used in this study. 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 was selected for all counties within the study area. Daily values of maximum and minimum air temperatures were taken from a single station that contained the most complete data in each county. 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 interpolated using the data from surrounding counties.

Heat Units and Potential Cotton Yield

For each county, annual heat units accumulated between planting and harvesting dates for cotton was calculated using Eq. [1]. A computer program in FORTRAN was written to automate the county-wide heat unit calculations for the study area. An annually variable planting date for cotton in each county was identified based on the predicted daily minimum soil temperature. Two sets of regression models reported in Esparza et al (2006) for the for Ogallala aquifer region were used to predict daily minimum soil temperature. One regression model is based on maximum air temperature and the other is based on minimum air temperature for each climatic division (NCDC, 2001). Annual cotton planting dates for each county were identified when its estimated daily minimum soil temperature during the planting season was above or equal to a threshold value of 15.6 ^{o}C for both statistical models. The first day of hard freeze or October 15, whichever occurs first, was selected as the harvesting date. This closely mimics observed planting and harvesting time in the Southern High Plains. Although the first frost may not occur during October, producers usually harvest their cotton before third week of October to avoid late season pests and fall precipitation events that affect fiber quality. In the Central and Northern High Plains, frost may occur during the last week of September and may kill the plant if not harvested.

Finally, the county-wide potential cotton yield (*PCY*; kg/ha) was calculated as:

$$PCY = 0 \qquad \text{when } THU < 800\ ^{o}\text{C} \qquad [2]$$

$$PCY = \left[\frac{THU - 800}{41.7}\right] \times 112.5 \qquad \text{when } 800 < THU < 1000\ ^{o}\text{C} \qquad [3]$$

$$PCY = \left[5 + \frac{THU - 1000}{41.7} \right] \times 112.5 \quad \text{when THU} > 1000\ ^{o}\text{C} \qquad [4]$$

where *THU* is the total heat units accumulated (^{o}C) during the growing season in a given year. The proposed equations are based on three assumptions: (1) *PCY* is equal to zero when *THU* is less than 800, (2) with 1000 heat units accumulated, the cotton plant will have one open boll with 4 more bolls at 85% maturity level and produces approximately 560 kg/ha (500 lb/ac) of cotton lint under irrigated conditions, and (3) with every additional 41.7 (75 ^{o}F) heat units, plant produces one more harvestable boll (Pers. Comm. D. R. Krieg). Equations 2, 3 and 4 were used to estimate *PCY* for counties with *THU* less than 800, in the range of 800-999 and above 999, respectively. With *THU* in the range of 800-999, cotton can be grown; however, it may result in low *PCY* and poor quality lint.

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 evaluate 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 potential cotton yields were ranked in decreasing order and the exceedance probability (*P*) was calculated as:

$$P = \frac{N}{(n+1)} \qquad [5]$$

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. The return period is calculated as the inverse of the exceedance probability. For example, a rainfall event with an exceedance probability of 0.5 will occur at least once in every two years.

A set of maps was made using Arcview 3.3 (ESRI, 2002) to understand the spatial distribution of heat units and potential cotton yield over the study area. It included county-wide long-term average heat unit and potential yield maps; and potential cotton yield maps with exceedance probabilities of 0.99 (1-yr RT) and 0.5 (2-yr RT). Finally, a county-wide estimate of potential reduction in irrigation withdrawls was made by switching 50 percent of the total corn acreage with cotton in counties that produce 562.5 kg/ha or more (or *THU* of 1000 ^{o}C or more) with a exceedance probability of 50 percent (2-yr return period).

RESULTS AND DISCUSSION

Using long-term (1971-2000) air temperature data, county-wide heat unit accumulation (*THU*) during the growing season and *PCY* for each year were calculated. For most counties, the planting dates were between May 1st and 15th. However, some counties around Lubbock in the Southern High Plains of Texas had planting dates between April 15th and 30th while counties in the east had planting date between May 25 and June 15.

The *THU*s were varied from 582 in Union County, NM to 1724 in Ector County, TX. As expected, the *THUs* were higher for counties located in southern part of Southern High Plains and lower in the Northern High Plains. There were 109 counties including all of the counties except Castro in the Texas High Plains, Oklahoma Panhandle, and southwestern Kansas counties recorded more than 1000 heat units. Only 2 out of 10 counties in Colorado recorded more than 1000 heat units. There were 14 counties in the study area (9 in Kansas) that recorded between 800-999 heat units.

County-wide annual average *PCY* showed a similar trend. The *PCY* varied from zero to 2507 kg/ha for counties with more than 800 heat units. The county-wide average *PCY* values were consistent with average cotton yield reported by Wanjura et al. (2002) for full irrigation treatment yield plots in Lubbock County, Texas.

Figure 2(a-b) illustrates potential cotton yield with 1- and 2-year return periods, respectively. Table 2 presents potential yield-wide distribution of counties under 1- and 2-year return periods. With the 1-year return period, the county-wide annual PCY varied from zero to 1744 kg/ha (Fig. 2a) with an average of 403 kg/ha. About 39 percent of all counties in the study area was estimated to have a PCY more than 500 kg/ha. The PCY varied between 500-1000 kg/ha for 33 counties and exceeded 1000 kg/ha for 18 counties with 15 of them from Texas. Only two counties along southern Kansas border exceeded 1000 kg/ha. However with 2-year return period, the county-wide annual PCY varied from zero to 2488 kg/ha (Fig. 2b) and averaged about 1024 kg/ha. This is about 1.5 times higher than that for 1-year return period indicating that producers may have a better chance to increase their net profit with yield goals that have the return period of 2 years. The annual PCY for 105 out of 131 counties in the study area exceeded 500 kg/ha indicating that cotton can be grown in a major portion of the study area (Table 2) when producers adopt a yield goal with a 2-year return period. The 66 counties with the PCY more than 1000 kg/ha were found along eastern half of the study area with 24 counties located in the south central Kansas (Fig. 2b) where corn is still the major crop of choice under irrigation conditions. This may be partly due to its lower elevation from the mean sea level.

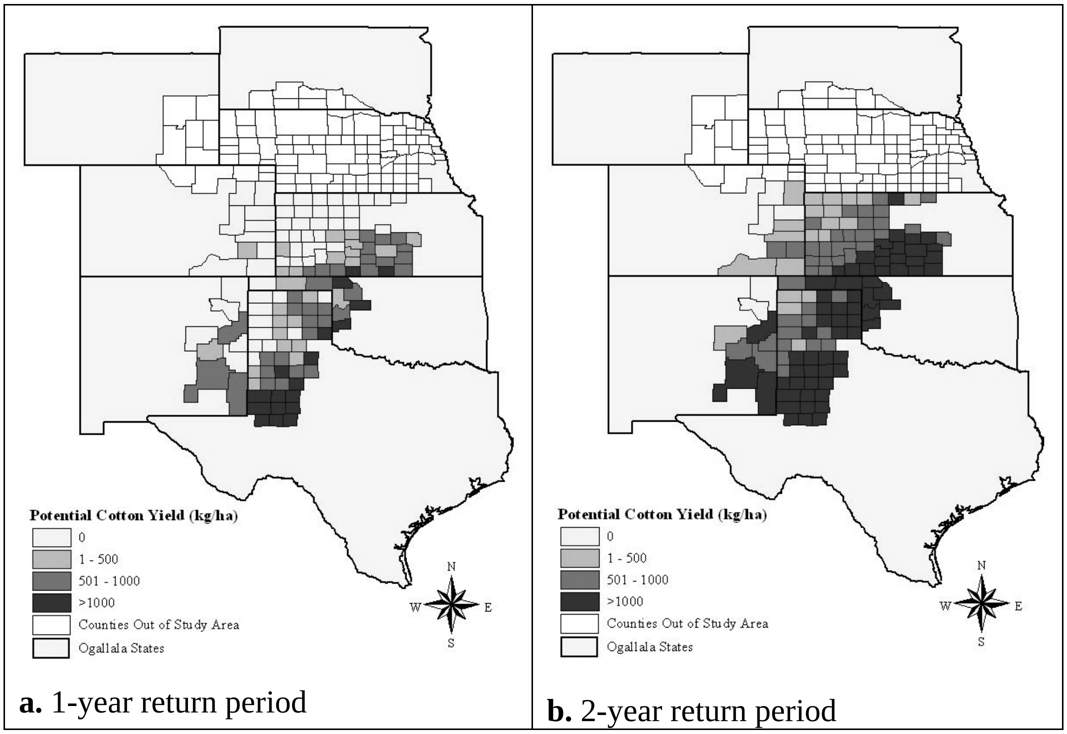

Figure 2. County-wide potential cotton yield in the study area with two different return periods.

Table 2. Potential yield-wide distribution of the 131 counties in the study area for 1- and 2-year return periods.[1]

Potential Cotton Yield (kg/ha)	Number of Counties	
	1-Year RP (P = 0.99)	2-Year RP (P = 0.5)
0	55	10
< 500	25	16
500-1000	33	39
> 1000	18	66

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

Figure 3 illustrates the county-wide potential water savings if producers were to switch about 50 percent of their total irrigated corn acreage to cotton in counties that had yield of at least 500 kg/ha cotton lint. This converts approximately 325,000 ha presently under irrigated corn (NASS, 2004) to cotton, and provides a potential annual reduction in withdrawal of ground water for irrigation purposes of about 60.4 million ha-mm. About 72 percent of the reduction in water use comes from Kansas counties, because of the relatively large area of irrigated corn and small area of cotton.

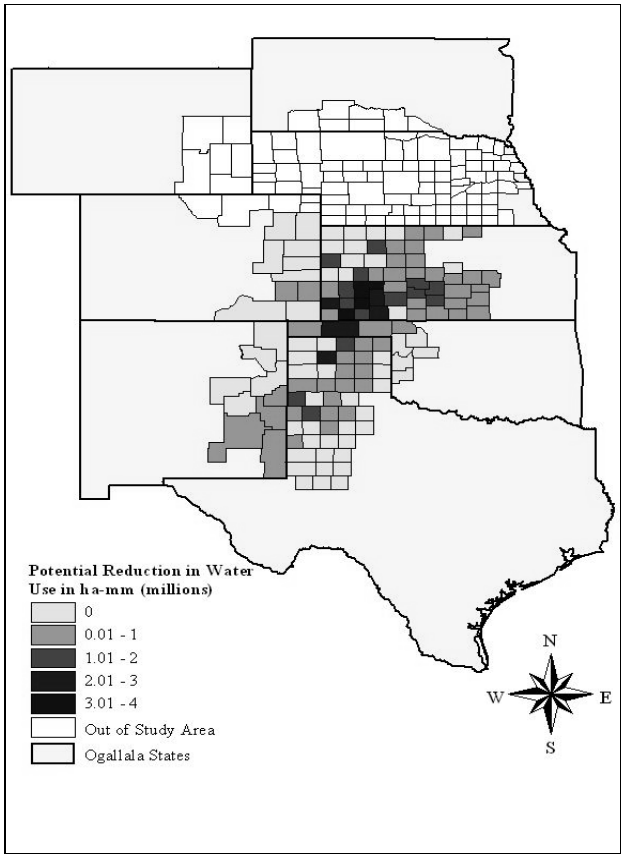

Figure 3. **C**ounty-wide potential reduction in irrigation water use when 50 percent of the irrigated corn acreage was switched to cotton.

CONCLUSIONS

The Ogallala aquifer under Central and Southern High Plains 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-tolerant and economically viable alternative crops. In this study, we evaluated the feasibility of growing cotton in the Ogallala aquifer region based on potential cotton yield. County-wide potential yield estimates over 30 years (1971-2000) indicate that most counties in Southern and Central High Plains provide suitable climatic conditions to grow cotton. Yield goals based on 2-year return period may give better profits to producers than yield goals with 1-year return period. Management uncertainties, however, on irrigation efficiencies, fertilizer and pest management may require further consideration to estimate potential yield. Nevertheless, these data show that cotton is a suitable alternative crop for the Central High Plains of the Ogallala aquifer region. Significant reduction in water withdrawals from Ogallala for irrigation is possible if producers were to switch 50 percent of their corn acreage to cotton.

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