ANALYSIS OF INTERRELATIONSHIPS BETWEEN CLIMATE CHANGE AND COTTON YIELD IN TEXAS HIGH PLAINS

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The Texas High Plains produces the most substantial amount of cotton in Texas. The region is a semi-arid area with limited precipitation, and it is, therefore, susceptible to climate change. Cotton production in the Texas High Plains is mostly dependent on irrigation to increase yield. The overall goal of this research was to study the interrelationships between climate change and cotton yield using correlation analysis and also to study how climate has changed in the region using trend analysis. A three-decade data (1987-2017) was analyzed to establish the relationship between climate change and cotton and also to determine how climate has changed in the area over the last 30 years. The research used precipitation and temperature data to assess climate change.

The results of this research showed that annual mean temperature has lesser impacts on cotton yield, and the correlation between annual precipitation and cotton yield is insignificant. It also found out that high rates of temperature at the boll opening stage of cotton growth results in decreased cotton yield and that at the boll development and boll opening stages, precipitation is needed. Again, the research indicated that, on average, there had been a significant increase in temperature, but precipitation trends are insignificant. About 60% of cotton acreage in the area is irrigated. Therefore the research also found out that increasing trends of cotton yield may contribute to the decline of groundwater in the area.

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CHAPTER 1

INTRODUCTION

1.1 Background

Cotton is a type of a cultivated plant that has found a variety of industrial uses. It is one of the world's most cultivated crops. Cotton is fluffy, soft seed hair fiber, which has a variety of species belonging to genus Gossypium. There are four cultivated species of cotton, namely, Gossypium arboreum, Gossypium herbaceum, Gossypium hirsutum, and Gossypium barbadense (Wendel & Grover, 2015). Cotton develops through different plant growing stages. The first stage is planting, followed by seedlings, leaf development, flowering and bowl development, bowl opening, and harvest (Wendel & Grover, 2015). The cotton plant belongs to the mallow or hibiscus family. It is a shrub that is native to the subtropical and tropical parts of the world. These regions include Asia, North America, South America, and Africa. The plant is grown in many parts of the world, consequently making cotton products inexpensive. During processing, the cotton fiber is put through spinning to form threads or yarns, which are then used to make textiles (Bosma, 2017).

1.2 Climate Change and Its Impact on Cotton Production

The response of cotton to the changing climate depends on which growth stage the plant is in; also, depending on the region at which the plant is grown, high rainfall rates may lead to a shorter growing season while higher temperatures may lead to longer growing season (ICAC, 2007). Extreme weather events are challenging to forecast and may influence the plants at any time of the season. Soils with lower temperatures during planting hinder the timely cultivation of cotton in some countries, and rising temperatures will help those areas as they can plant their cottonseeds much earlier than expected (ICAC, 2007).

Contrarily, cotton-producing areas with higher temperatures are negatively affected by the rising temperatures; higher temperatures result in increased shedding of flower buds (ICAC, 2007). The rise in temperature can also have a positive impact on cotton yield, areas with rising temperature have the effective fruiting period squeezed between two phases of lower temperatures: one begins early in the season to start successful flowering and boll maturation, and the other is at maturity, and this leads to the termination of fruit formation (ICAC, 2007). Boll retention in cotton production is more responsive to high temperatures, it is impossible to avoid the impacts of high temperatures, and so this condition can result in bud shedding, which is the most usual reason for the loss of fruit forms (Reddy et al., 1999). According to Reddy et al. (1999), boll size and its maturation period are reduced as temperature increases.

As the third-largest producer of cotton and largest cotton exporter, the United States of America (USA) has four vast cotton growing areas: the west (9%), southwest (35%), mid-south (34%) and southeast (22%), and these regions together are called the cotton belt (Cotton Incorporated, 2009). In the USA, cotton production is immensely merchandised and fuel dependent. Cotton yield is anticipated to rise with limited increases in temperature and carbon dioxide; however, the number of scorching days is expected to increase which may cause adverse impacts on cotton yield (ICAC, 2007). The impacts of climate change on rainfall differ per region. The southeast and mid-south regions are the mostly rain-fed cotton areas, and they may experience an increase in precipitation but a rise in extreme weather events. In the west and southwest, cotton production primarily relies on irrigation (Ton, 2011). According to Karl et al. (2009), the availability of water will become a more significant issue due to groundwater depletion and reduced and more aberrant snowmelt from the Rocky Mountains.

1.3 Cotton Production in Texas

Cotton is a much-cultivated crop that has a significant economic impact. Cotton production in the USA is a 25 billion dollar industry per year, and it employs over 200,000 people as against a growth of 40 billion lbs a year from 77 million acres of land (Yafa, 2006). The estimate of cotton production in the USA as of 2012 was 17.31 million bales (cotton newsline.org). In 2019, cotton production in the USA estimated 20.2 million bales (Meyer, 2019).

Texas is the largest cotton production state in the USA; it produces about 25% of the nation's cotton on more than 6 million acres, which are equivalent to over 23,000 square kilometers of cotton fields (cotton newsline.org). The Texas High Plains (THP) produces the most substantial amount of cotton in the State; this region is divided into the Panhandle and the South Plains. The South Plains is made up of 19 counties, and it is the largest cotton-producing region in the world, with an acreage exceeding three million in some years (Yafa, 2006). Aside, cotton production, the area produces other crops: corn, sorghum, wheat, and peanuts. The THP receives limited precipitation of about 18 inches on the average per year (Closas and Molle, 2018). About 60% of cotton acreage is irrigated in the THP, but this number varies with the location (Weinheimer et al. 2013). In the THP cotton is planted in May and harvested in October through December. Irrigated cotton fields produce an average of 500 – 1500 lbs of lint per acre, which is based on the climate and irrigation capacity; dryland cotton farming produces an average of 270 lbs of lint per acre (Ruckebusch, 2012).

1.4 Problem Statement

Although the THP is a semi-arid region with limited precipitation, the area is known to be the major agriculture producer of irrigated crops because the area is found within the confines of the Ogallala aquifer. THP produces 3% - 5% of global cotton and cottonseed and 20%-30% of national cotton and cottonseed (www.plainscotton.org). Cotton farmers in Texas High Plains mostly depend on groundwater as an irrigation source due to the semi-arid nature of the region.

The source of groundwater is mostly from the Ogallala Aquifer, which is a major aquifer in the region. Ogallala aquifer formation is dated back to millions of years ago and was formed from the erosion of the Rocky Mountains. The aquifer travels through eight states: Wyoming, Texas, South Dakota, Oklahoma, New Mexico, Nebraska, Kansas, Colorado, and this aquifer provides 30 percent of water for the United States' irrigation (Closas and Molle, 2018). The Ogallala aquifer covers 174,000 sq. miles and it irrigated 3.5 million acres of farmland in the 1950s, and it is irrigating 16 million acres today (Guru et al., 1970). It has been the primary source of irrigation since the year 1950, and the process of extracting groundwater accelerated when the technology of groundwater extraction became affordable. The extracted water became the source for irrigation for various crops, including cotton in the Texas High Plains (Closas and Molle, 2018).

It is popularly assumed that due to climate variability, groundwater levels in the irrigated agricultural production regions will go down in the coming decades because most of groundwater will be used as water source for the crop irrigation. For instance, a study conducted by Hanjra and Qureshi (2010) suggested a global shortage of water for irrigation purposes in the future because of water competition by non-agriculture uses. According to Bomar (1983), the Northern High Plains in the United States has a semi-arid climate is susceptible to drought. Also, Wentz et al. (2007) predicted that wet regions are becoming wetter, while dry regions are becoming drier, and this implies that the High Plains region, which is susceptible to drought, will become drier in the coming decades. This situation has the potential to affect cotton yield in the THP negatively. Therefore, it is necessary and crucial to study the impact of climate change on cotton yield in the THP in the past 30 years.

The literature reviewed so far seek to suggest a damaging effect of climate change on cotton production, especially in arid and semi-arid regions. However, other literature also suggested that cotton plants can withstand climate variability. For instance, Ray et al., (2018) suggest that drought has a lesser impact on cotton and sorghum production after having a comparative analysis on drought impacts on four crops (cotton, sorghum, winter wheat and corn). With this gap in the literature, this study will analyze a three-decade data to establish the relationship between cotton yield and groundwater levels and climate change in the THP. Hence, the main problem to be addressed in this study is how climate change affects cotton production in the High Plains of Texas.

As a justification, some literature suggested that groundwater levels will go down in the next decades because of rapid groundwater withdrawal for irrigation to meet the increasing water demand for agricultural production; therefore, it is imperative to analyze data from the last three decades to ascertain whether or not there is a significant relationship between groundwater levels and cotton production. Thus, this research will determine if increasing trends of cotton yield lead to the decline in groundwater resources in Texas High Plains. The outcome of this study will help policymakers and farmers to adopt new strategies to deal with climate change if it has adverse effects on cotton production in the study area. This thesis answers three specific questions:

1. How has climate change in Texas High Plains been in the past 30 years? This question will help us to know whether or not there has been climate change in THP.

2. What are the impacts of climate change on cotton yield? Since the THP is a semiarid area and more susceptible to climate change, and also significant in cotton production, it is important to understand if changes in climate had impacted cotton yield.

3. How does cotton yield relate to groundwater level change? The THP receives limited precipitation, due to this, agriculture in the area depends on groundwater for irrigation. It is important to know if increasing trends of cotton yield lead to a decline in groundwater.

1.5 Objectives

The first objective of this research is to analyze the impacts of climate change on cotton yield in the THP. To do this, the study collected data on cotton yield in the THP as well as climate data (precipitation and air temperature). Using a linear regression equation, a trend analysis was carried out to identify the trends of precipitation and air temperature in the area. A correlation analysis was also done to determine how precipitation and air temperature correlate with cotton yield. Hence, this study is important for understanding if cotton can withstand the changing climate without reducing cotton production in the future.

Moreover, the research, examines how the climate in THP has changed over the past years. Again, precipitation and air temperature data were collected for this objective and a trend analysis was done using a linear regression equation to determine how these climate variables (precipitation and air temperature) have changed over time. According to Karl et al. (2009), the THP region has experienced climatic changes such as decreased rainfall, increased temperature as well as increased the frequency of severe occurrences of storms, wildfires, and extreme precipitation occurrences in the past decades.

Lastly, the research assesses the correlation between groundwater and cotton yield in THP. To do this, groundwater data was collected and correlated to cotton yield data using correlation analysis to examine whether increasing trends of cotton yield lead to a decline in groundwater. Most counties in the THP depend on the Ogallala Aquifer for groundwater to irrigate their crops, and the amount of precipitation received in the area determines how much of groundwater will be used for irrigation.

1.6 Significance of the Study

The results of this research can improve our understanding of the relationship between cotton yield and climate variability, and thereby providing farmers with the impacts of climate change on cotton yield, and this will help them to adopt management strategies to mitigate climate change effects when the need arises. Since the THP is a semi-arid area with limited precipitation, the study will also assist policymakers to come up with a more resilient policy framework for cotton farming in the area.

CHAPTER 2

LITERATURE REVIEW

2.1 Climate Change in Texas High Plains

The planet is becoming warmer as the day goes by, and the climate is changing. This event of climate change has been occurring on diverse scales of space and time, and it is the ordinary affairs for the climate-atmosphere system (Mearns, 2000). There is a significant growth in activities that are related to changes in land and energy use during the last century, and this has contributed to an anthropogenic climate change. Carbon dioxide concentrations in the atmosphere have increased by 28% or more since the beginning of the industrial revolution, and it is mainly because of burning fossil fuels, as well as deforestation (Reicosky et al., 2000, Houghton et al., 2001). Future scenarios of atmospheric greenhouse gases indicate the carbon dioxide could increase from current levels of 360 ppm to between 540 and 970 ppm by the end of the 21st century (Houghton et al., 2001).

General Circulation Models (GCMs) has predicted that by the end of the 21st century, an increase in global temperature would range from 1.4 to 5.8˚C due to the projected increase in the concentrations of greenhouse gases. Due to this, it shall be difficult to determine the climate pattern within any region in the world since they will become more variable. In the United States, the rate of future warming is anticipated to be faster than the mean global rate with a frequent occurrence of scorching temperatures (Houghton et al., 2001).The Texas High Plains is a productive agricultural zone of the State that produces various crops like wheat, cotton, sorghum, and corn. (Colaizzi et al., 2009). The region comprises of a wide range of ecosystems that include marshes, forests, deserts, and rangelands (USGCRP, 2014). Historically, climate changes that have occurred in the THP have posed a significant threat to agriculture viability and have additionally altered agriculture through changes in yields and irrigation requirements. The Texas High Plains is also characterized with a limited hydrologic resource and is among the regions that heavily rely on water that comes from the Ogallala aquifer in the production of irrigated field crops like sorghum, wheat, cotton, and corn (Findikakis, 2011). Weinheimer et al. (2013) showed that the THP each year used around 5.7 million acre-feet of water to sustain about 4.6 acres of irrigation land.

The introduction of irrigation techniques in THP has been significant in maintaining high crop yields and protecting the yields against disasters like drought. Water drawn from the Ogallala aquifer has played an essential role in allowing the THP to be an agriculturally productive region, and due to changes in climate, the current water use has significantly become unsustainable, with water extracted annually becoming higher than annual recharge. A recent study by McGuire (2014) on the THP suggested that the levels of water in the Ogallala aquifer from the year 1950 to the year 2013 declined 158.2 million acre-feet. The decline of the Ogallala aquifer caused by the climatic changes in the THP is likely to have a significant impact on agriculture production. Additionally, according to Karl et al. (2009), severe weather patterns and historical climate changes have been proven in impacting the production of agriculture negatively with future predictions suggesting that the effects are projected to worsen by the year 2100.

Climate change in the Texas High Plains is rapidly occurring and simultaneously having an effect. Hence, the climatic changes are a result of human actions, and the individuals inhabiting these areas feel the human-made effects. Also, the dramatic elevation changes throughout the area, produces a high amount of variety in climate, environment, and geography (Schmandt, 2011). The effect of climate change in the THP includes changes in drought and flooding, the spread of invasive species and rising temperatures. Major areas affected by the climatic changes include indigenous communities, agriculture, water, energy, and tourism (U.S. Global Change Research

Program, 2009). Adequate, safe supply of water is highly essential in the THP since water is the lifeblood there, and effective management of the hydro resource is paramount. Small climatic changes have significant impacts that make the management of the resource a challenge, and futuristic climate changes have a likelihood of accelerating the challenges.

Apart from affecting water supply, climate changes take a toll on shaping agricultural production in the THP. These changes in extreme weather patterns and the rise in temperatures have a high likelihood of causing adverse impacts. In response to these, food producers are forced to manage their operations that include shifts in agricultural practices and enterprises. The impacts of climate change in the Texas High Plains are not only limited to agriculture but also some economic effects. It is clear that the local economy which depends on a river or winter-based recreational activities, have been greatly affected by the change in climate in this region. Climatic changes based on agricultural production in these areas produce a domino effect for recreation, native species, and wetlands (Carlson, 2005). Likewise, the reduction of grassland areas in the prairie has been due to climatic changes.

Aside from climate change having adverse impacts on agriculture in THP, Individuals who live in the area are also at risk. Most of the communities have become proactive in strategic climatic change planning and adaptation. The changes result in harmful effects on livelihoods, tribal economies, and sacred plants and waters that are always used in ceremonies, subsistence, and medicine (Maldonado et al., 2014). Climate change in the THP has contributed to the poor air quality and it has also affected the pollen season.

Projections in climate change suggest that future precipitation could change across the region and at local scales (Norwine, 2014). Additionally a projection report done by the United States Global Change Research Program suggests that the entire region will receive less precipitation during summer (U.S. Global Change Research Program, 2009). Moreover, the report suggests that temperatures in the Texas High Plains have risen drastically by -16.9°C (1.5°F) using the 1960's and 1970's as a baseline and are projected to increase further between -16.4°C(2.5°F) to -10°C by the end of the century, subject on the scenario of emissions. During summer,, there are expected changes, and they are further noticeable with intense and frequent heatwaves expected to changes in climate (Karl et al., 2009). Climatic changes have caused trauma to the wildlife inhabiting the THP. Increased temperatures combined with precipitation shifts and previous snowpack losses are projected to raise summer drought situations in the afforested parts of the region, increasing forest fires risks (Lambin et al., 2006).

Increased heat and drought due to climatic changes, has intensified the evaporation rates from the numerous playa lakes and the prairie potholes. The playa lakes play a vital role in recharging the aquifer (Smith, 2003). These shallow water bodies have shrunk drastically, affecting migration stopover and the breeding of species like the frogs, cranes, geese, ducks, and the invertebrates. So the loss of these playa lakes creates additional stress on the Texas High Plains water reserves.

2.2 Climate Change Impacts on Cotton

Cotton is a major crop that is grown in the THP region. The production of cotton in the region faces harsh challenges due to a rapid decline of groundwater levels in the Ogallala aquifer (Musick et al., 1988; Colaizzi et al., 2009; Chaudhuri and Ale, 2014); and increases in groundwater pumping costs (Colaizzi et al., 2009). Additionally, studies on climate change in this region predicts warmer summers and reductions in annual precipitation in the future (Nielsen-Gammon, 2011; Modala, 2014). Such trends necessitate larger groundwater withdrawals to meet higher evapotranspiration needs of cotton.

Cotton plants grow at temperatures ranging from a minimum of 12 to 15˚C to an optimum of 26 to 28˚C, and higher plant- sustainable temperature depends on the duration of exposure (Reddy et al., 1997b). The short period before, during, and immediately after flowering is the most sensitive yield-related period for high temperatures. The efficiency of fruit production in cotton increases with temperatures up to 29˚C and then reduces abruptly with higher temperatures, possibly because net photosynthesis is less at both higher and lower temperatures than at optimum (Reddy et al., 2000). Bolls are produced by cotton plants till photosynthetic requirements can no longer support new fruit. When the photosynthetic requirements are met due to fruit maturation, vegetative growth resumes. Plants grown by higher temperatures (above 32˚C) indicate luxuriant vegetative growth due to premature boll abscission (Reddy et al., 1997b, c). Hastening of development, especially during the boll-filling period, is also caused by high temperatures, hence resulting in smaller bolls, lower yields, and poor lint quality (Hodges et al., 1993; Reddy et al., 1999).

Photosynthesis, photorespiration, dark respiration, and transpiration are plant processes that are directly affected by changes in atmospheric carbon dioxide (Fitter & Hay 1987). Leaf and canopy photosynthesis is generally improved by elevated carbon dioxide due to increased concentrations of ribulose-1, 5-bisphosphate carboxylase, and suppression of photorespiration in C3 plants such as cotton (Reddy et al., 2000). In addition to this, partial closure of the stomata is as a result of higher atmospheric carbon dioxide (Morison 1987), therefore indirectly increasing tissue temperature and reducing leaf-level transpiration. A 30% decrease in transpiration has been reported for plants grown in atmospheres with doubled carbon dioxide (Kimball & Idso 1983, Rosenzweig & Hillel 1998). This potential reduction in transpiration with increased photosynthesis leads to water use efficiency under elevated CO_2 conditions (Reddy et al., 2000). Kimball (1983) analyzed 430 reports dealing with plant response to elevated CO2 and concluded that doubling of atmospheric CO2 on average would cause a 33% increase in yield in C3 crops. Growth rates are, although sensitive to elevated CO2, emergence to reproductive initiation, major cotton phenological events, the square period, and ball maturation period are not affected by CO2 (Reddy et al., 1996, 1997a,b).

Regions and sectors are affected by climate change in different ways (Klein et al., 2005), a year-to-year and area-to-area change in crop production is a result of the amount of rainfall, sunshine hours, temperature, relative humidity, and the length of a climate period. Over time, these climatic factors are changing, having mixed effects on agriculture. This variability in climatic factors is due to environmental changes, economic, and social changes that affect the agriculture sector of a country. Therefore, variability in climatic factors leads to vulnerability in agriculture (Alam et al., 2019). The agricultural sector employs half of the world's workforce and dominates the economies of 25% of the world's countries. Also, it accounts for 24% of the world's agricultural output and uses 40% of the land area (Food and Agriculture Organization, 2003). Changes in climate affect important factors of agriculture and also climatic factors such as rainfall, temperature, and relative humidity (Alam et al., 2019).

Responses of crops to the environment vary from region to region based on soil type, plant type, and regional weather. Anticipated higher temperatures would be favorable to the colder parts of the world due to a longer growing season. In the warmer regions, higher temperatures would result in hastened development and reduced yields, mostly during the critical growth periods in summer (Rosenzweig & Hillel 1998). The most important weather forecast variable to change due to anthropogenic causes is temperature; however, the relations of weather and soils and precipitation are also significant determinants of agricultural productivity. There is a high level of uncertainty relating to the effects of climate change on crop processes and yield; this is due to a lack of information necessary to understand crop responses to global warming (Reddy et al., 2002). The probability, frequency, and severity of extreme climate conditions are, therefore, vital to society (Rosenzweig & Parry 1994, Houghton et al., 1996).

2.3 Relationship between Cotton Yield and Groundwater

A variety of factors affect crop yield, including climate, availability of water, and diseases or pets. Therefore, it is essential to know which factors influence the yield and the risks presented. With regards to cotton yield, factors can be either climatic or inputs. According to Bakhsh et al., (2005), inputs such as land preparation, seed, irrigation, education, and plant protection were contributing factors towards higher cotton yield. Other studies (Hanson et al., 1991; Nabi 1991; Iqbal et al., 2001) also showed a relationship between these factors and cotton yield. Bednarz et al., 2006 suggest that the adjustment of plant density also enhances cotton yield, while Siebert et al., 2006 also suggest that the establishment of acceptable cotton seedlings paramount for high. Researchers have shown that an estimated 53% of the global cotton field uses irrigation, producing 73% of the world's cotton (Soth et al., 1999). However, the challenges in these areas limiting cotton yield are drought and salinity (Zhang et al., 2012). The global climatic change will likely affect this situation, in turn, affecting future crop yield. Moreover, effective irrigation management will enhance and reduce the effects of drought and salinity on cotton yield.

The purpose of irrigation is to keep water status at a level that increases the yield of cotton during water stress. Irrigation method such as the drip irrigation system is the most efficient type in terms of water use and higher yields in semiarid and arid areas as stated by many researchers compared to the conventional irrigation methods (Wanjura et al., 2002). Due to the water scarcity in these semiarid and arid areas, optimum utilization of surface and groundwater is crucial to examine. Groundwater is a flexible and reliable source of water for irrigation. Several studies show groundwater as a significant contributing element of water balance and for crop evapotranspiration. For example, Kahlown et al., (2005) studies on the effect of shallow groundwater on crop water requirement and yield showed that groundwater contribution to crop water requirements varies with the depth of the water table. Whereas at a depth of 0.5m, wheat met its entire water requirement from groundwater, the yields of maize and sorghum were reduced with a higher water table. From the studies, the overall optimum water table depth for all the studied crops was from 1.5 to 2.0m. Another study also found groundwater contribution of daily crop water used to be up to 40% (Soppe and Ayars 2003). Since salinity affects cotton yield, Hutmacher et al., 1996, conducted a 3-year column lysimeter experiment to determine the influence of shallow groundwater salinity on groundwater uptake by cotton. In this study, the treatment of groundwater salinity was 20 dS m-1; the contribution of groundwater of the total seasonal evapotranspiration was about 30 to 42%; however, it declined to 12 to 19% of total evapotranspiration at higher salinity levels. Though cotton is a salt-tolerant crop, it can as well be affected by lower or higher levels of salinity of water, which affects growth and yield. Again, 1.84m is the required seasonal averaged groundwater depth of the experiment field, but the depth of the groundwater table determines the nature of effects, either positive or negative effects on cotton growth (Han et al., 2015).

To understand and evaluate how groundwater table depth affects cotton, Han et al., 2015 analyzed the influence of groundwater on the seasonal maximum leaf area index, the average seasonal water stress, cotton yield, actual transpiration, actual evaporation, and capillary rise. The study revealed that cotton growth and other components of soil water balance depends on the groundwater table. For example, there was a significant impact of cotton growth on the capillary rise from groundwater. Based on some other studies such as the above, shallow groundwater recognized as the potential water resource for crop use, especially cotton (Han et al., 2015). While some studies show positive effects of shallow groundwater (Soppe and Ayars 2003), others such as Soylu et al., (2004) state that disproportionate in capillary rise from groundwater can cause an increase in soil evaporation and salinity. Also, shallow groundwater can affect the physiological function of cotton, causing mortality, which tends to affect yield (Zaidi et al., 2014).

In agricultural production, water value is an essential factor. However, in the United States, there is a competition for water resources between the municipal, industrial, and agricultural sectors. Following this, many agricultural practices, primarily cotton production, uses the irrigation system. Irrigation accounts for 70% of the world's freshwater withdrawals and about 90% water use (Siebert et al., 2010). During drought, aquifers serve as primary buffers that host groundwater for cotton production. According to Siebert et al., (2010), a new global inventory of irrigated areas with groundwater, surface water sources, and the related consumptive uses were presented. From the data used in this work, the most significant extent of areas with groundwater as irrigation sources were India, China, and the United States. These areas produce the most substantial cotton in the world. Due to the complicated dynamic exchange of the hydrological cycle between groundwater and surface water, surface water is likely to seep into groundwater to recharge aquifers. As groundwater is prone to pollution than surface water, pollutants may flow into groundwater, causing affecting cotton growth. For example, gradual withdrawal of salt from the ocean and soil water into groundwater may increase the salinity of groundwater, causing growth effect, which decreases yield. Also, any other pollutants such as excessive industrial fertilizers (nitrates) may release nitrous oxide, which is highly destructive into the soil and water bodies, and chemicals may seep into groundwater, reduce soil nutrient, and water retention capacity resulting in a decline in cotton yields.

The effect on cotton yield depends on the availability of water or water value, therefore, since groundwater level plays a crucial role in irrigation systems as a source of water for cotton production, it is imperative to analyze the extent of groundwater level or changes such as salinization and water table depth that affects cotton yield.

CHAPTER 3

METHODOLOGY

The study will make use of quantitative data analysis with the view that phenomenon is best understood using quantitative techniques (Creswell, 2003).

3.1 Study Area

Texas High Plains is the study area for this research, which spread over a large area of approximately 22 million acres. Annual precipitation in this region ranges from 36 cm in the west to 61 cm in the east, and annual mean high temperature in this region is 75°F, while average mean low temperature is 45°F (Modala, 2014). This region is also known as the Texas panhandle region with a relatively flat treeless terrain and a semiarid grassland ecosystem. It is essential to put the proposed study area into a national and global context, especially with regards to the climatic conditions of the High Plains. According to the Plains Cotton Growers, Inc (PCG), statistical data available in 2016 indicates that the United States is the world's third-largest producer of cotton and the largest exporter of cotton in the world. The State of Texas produces about half of the cotton produced in the entire United States. In Texas, the High Plains produces about two-thirds of cotton and cottonseed. The data shows that the High Plains produces about 20% to 30% of national cotton and cottonseed. Moreover, the area produces about 3% to 5% of global cotton and cottonseed. Hence, the High Plains is very significant in terms of cotton production.

For this study, 14 counties were randomly selected in the THP region including Bailey, Briscoe, Castro, Cochran, Crosby, Dawson, Deaf Smith, Floyd, Gaines, Hockley, Lynn, Parmer, Swisher and Terry. Figure 3.1 shows the locations of these fourteen counties.

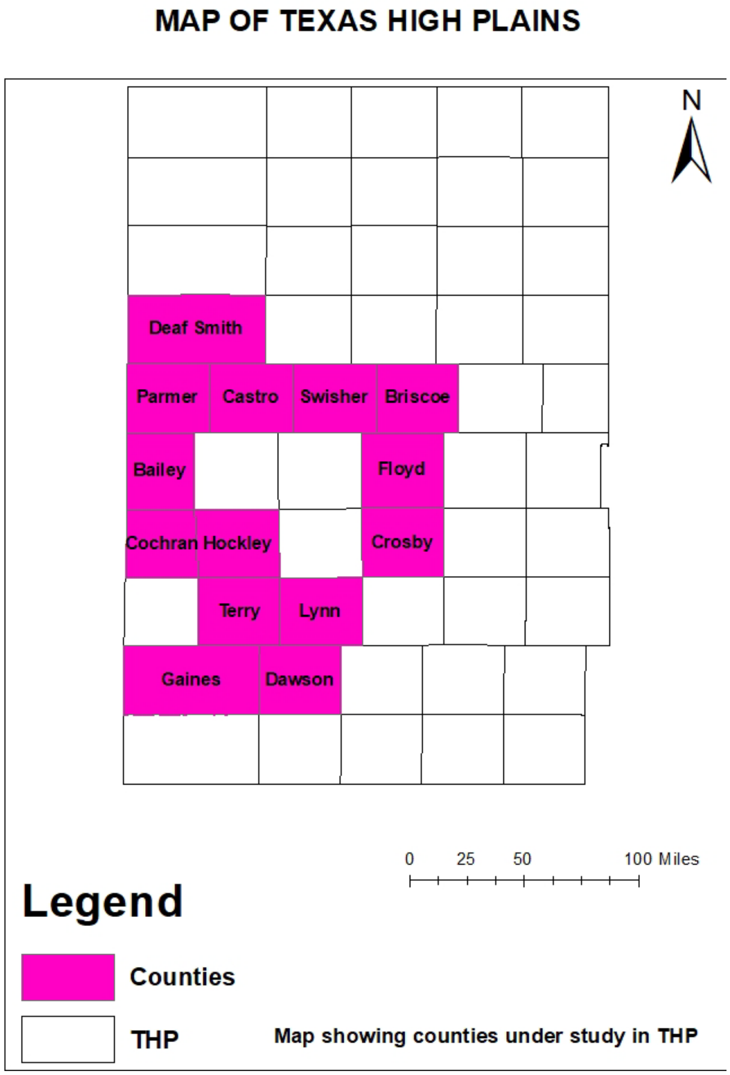

Figure 3.1: Fourteen counties in the Texas High Plains

3.2 Data Description and Sources

The county based cotton yield data was downloaded from the United States Department of Agriculture, USDA (usda.gov). Climate data including daily precipitation and daily air temperature in each county were downloaded from the National Climatic Data Center, NCDC (ncdc.gov). Lastly, groundwater data is from the United States Geological Survey, USGS (usgs.gov). All of these data sets were compiled for each county and in the period of 1987 to 2017.

3.3 Data Analysis

The trend analysis was applied to determine the trends of cotton yield, precipitation, and the temperature over the past 30 years as shown in Equation (1). These variables are denoted by *y*, *t* is the time, *a* is the annual slope of the trend, and *b* is the intercept.

$$y=at + b \qquad \text{(Eq. 1)}$$

The correlation analysis was used to determine if there is a correlation between cotton yield and other variables such as precipitation, air temperature, and groundwater level. The correlation coefficient equation is given as below:

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}} \qquad \text{(Eq. 2)}$$

where *r* is the correlation coefficient, *n* is the number of observations, *x* is the first variable, and *y* is the second variable.

The study uses ArcMap to conduct spatial analysis of precipitation and temperature trends as well as their correlations to cotton yield. The correlation between groundwater and cotton yield is also mapped using ArcMap.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Annual Precipitation and Mean Temperature Trends and Their Correlations with Cotton Yield

Table 4.1 shows the results of annual precipitation and annual mean temperature trend analysis for the various counties during the past 30 years. The research uses annual precipitation and annual mean temperature trends to determine how climate has changed from 1987 to 2017 for these counties in the THP. The climate change results was obtained using trend analysis and the results on the impacts of climate change on cotton yield was obtained using the correlation analysis.

Table 4.1: Annual precipitation and mean temperature trends and their correlation with cotton yield

County	Precipitation trend (mm/year)	Correlation between P&CY	Temperature trend (°C/year)	Correlation between T&CY
Bailey	0.1260	0.3392	-0.0022	-0.1650
Briscoe	0.7306	0.2296	0.04200**	0.1493
Castro	2.1260	0.0282	0.0417**	-0.4489**
Cochran	0.9468	0.3007	0.0427**	0.2367*
Crosby	1.642	0.2928	0.0344*	0.0254
Dawson	-2.3099	0.1398	0.0110	-0.1529
Deaf smith	0.5982	0.0126	0.0382**	-0.3427*
Floyd	0.3747	0.1574	0.0360**	-0.2737*
Gaines	-3.0819	0.2137	-0.0086	0.0395
Hockley	0.1459	0.2468	0.0196	-0.0575
Lynn	3.1472	0.2731	0.0534**	0.1951
Parmer	0.7838	-0.0050	0.0433**	-0.3256*
Swisher	0.1987	0.1040	0.0072	0.1345
Terry	1.1977	0.2882	0.0287**	-0.0206

**p<0.01, very significant; *p<0.05, significant; p>0.05 insignificant

According to Table 4.1, Bailey county has a precipitation trend of 0.1260 (p>0.05) and a temperature trend of -0.0022 ($p>0.05$). The precipitation and temperature trends are insignificant for this county; from the trend results, there has not been any significant change in climate for this county from 1987 to 2017. The correlation between precipitation and cotton yield is 0.3392 ($p>0.05$), and the correlation between temperature and cotton yield is -0.1650 ($p>0.05$). Annual precipitation and annual average precipitation both have an insignificant impact on cotton yield.

Briscoe county shows a precipitation trend of 0.7306 ($p>0.05$) and a temperature trend of 0.0420 ($p<0.01$). The precipitation trend for the county is insignificant, while the temperature trend is very significant. The correlation between precipitation and cotton yield is 0.2296 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1493 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield even though the trend for temperature is very significant.

In Castro County, the precipitation trend is 2.126 ($p>0.05$), and the temperature trend is 0.0417 ($p<0.01$). The precipitation trend for this county is insignificant, while the temperature trend is very significant. Like Briscoe County, there have been some changes in air temperature since the trend is very significant. The correlation between precipitation and cotton yield is 0.0282 ($p>0.05$), and the correlation between temperature and cotton yield is -0.4489 ($p<0.01$). Precipitation has an insignificant impact on cotton yield, but the temperature has a very significant impact on cotton yield.

There is an insignificant precipitation trend of 0.9468 ($p>0.05$) and a very significant temperature trend of 0.0427 ($p<0.01$) for Cochran County. The correlation between precipitation and cotton yield is 0.3007 ($p>0.05$), and the correlation between temperature and cotton yield is -0.2367 ($p<0.05$). The temperature has a significant impact on cotton yield, but the impact of precipitation on cotton yield is insignificant.

The precipitation trend for Crosby County is 1.642 ($p>0.05$), and the temperature trend is 0.0344 ($p<0.05$). The correlation between precipitation and cotton yield is 0.2928 ($p>0.05$), and the correlation between temperature and cotton yield is 0.0254 ($P>0.05$). The precipitation trend for this county is insignificant, and precipitation has an insignificant impact on cotton yield. The trend for temperature is significant, but the temperature has an insignificant impact on cotton yield.

Dawson county shows a precipitation trend of -2.3099 ($p>0.05$) and a temperature trend of 0.0110 ($p>0.05$). Both precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.1398 ($p>0.05$), and the correlation between temperature and cotton yield is -0.1529. Temperature and precipitation have an insignificant impact on cotton yield for this county.

In Deaf Smith County, the precipitation trend is 0.5982 ($p>0.05$), and the temperature trend is 0.0382 ($p<0.01$). The temperature trend in this county is very significant, while the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.0126 ($p>0.05$), and the correlation between temperature and cotton yield is -0.3427 ($p<0.05$). Precipitation has an insignificant impact on cotton yield, but the temperature has a significant impact on cotton yield.

There is a precipitation trend of 0.3747 ($p>0.05$) and a temperature trend of 0.0360 ($p<0.01$) in Floyd county. The correlation between precipitation and cotton yield is 0.1574 ($p>0.05$), and the correlation between temperature and cotton yield is -0.2737 ($p<0.05$). The trend for precipitation in this county is insignificant, and precipitation has an insignificant impact on cotton yield. The trend for temperature is very significant, and the temperature has a significant impact on cotton yield.

Gaines county shows a precipitation trend of -3.0819 ($p>0.05$) and a temperature trend of -0.0086 ($p>0.05$). Both precipitation and temperature have an insignificant trend. The correlation between precipitation and cotton yield is 0.2137($p>0.05$), and the correlation between temperature and cotton yield is 0.0395($p>0.05$) both precipitation and temperature have an insignificant impact on cotton yield.

The precipitation trend for Hockley County is 0.1459 ($p>0.05$), and the temperature trend for the county is 0.0196 ($p>0.05$). There is an insignificant trend for both precipitation and temperature. The correlation between precipitation and cotton yield is 0.2468 ($p>0.05$), and the correlation between temperature and cotton yield is -0.0575 ($p>0.05$). There is an insignificant impact on cotton yield from precipitation and temperature.

In Lynn County, there is a precipitation trend of 3.1472 ($p>0.05$) and a temperature trend of 0.0534 ($p<0.01$). The temperature trend for the county is very significant, while the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.2731($p>0.05$), and the correlation between temperature and cotton yield is 0.1951 ($p>0.05$). There is an insignificant impact of precipitation and temperature on cotton yield.

Parmer County has a precipitation trend of 0.7838 ($p>0.05$) and a temperature trend of 0.0433 ($p<0.01$). The precipitation trend for the county is insignificant, while the temperature trend is very significant. The correlation between precipitation and cotton yield is -0.0050 ($p>0.05$) and the correlation between temperature and cotton yield -0.3256 ($p<0.05$). Precipitation has an insignificant impact on cotton yield, and the temperature has a significant impact on cotton yield.

There is a precipitation trend of 0.1987 ($p>0.05$) and a temperature trend of 0.0072 ($p>0.05$) in Swisher County. Both precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.1040 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1345. There is an insignificant impact on cotton yield from precipitation and temperature.

Terry County shows a precipitation trend of 1.1977 ($p>0.05$) and a temperature trend of 0.0287 ($p<0.01$). There is an insignificant trend for precipitation, but that of temperature is very significant. The correlation between precipitation and cotton yield is 0.2882 ($p>0.05$), and the correlation between temperature and cotton yield is -0.0206 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield.

4.1.1 Spatial Analysis of Annual Precipitation Trend

Generally, by looking at Figure 4.1, the dark green color represents counties with higher positive precipitation trends, and light green colors represent counties with lower positive precipitation trends. Dark blue colors represent counties with higher negative precipitation trends, and light blue colors represent counties with lower negative precipitation trends.

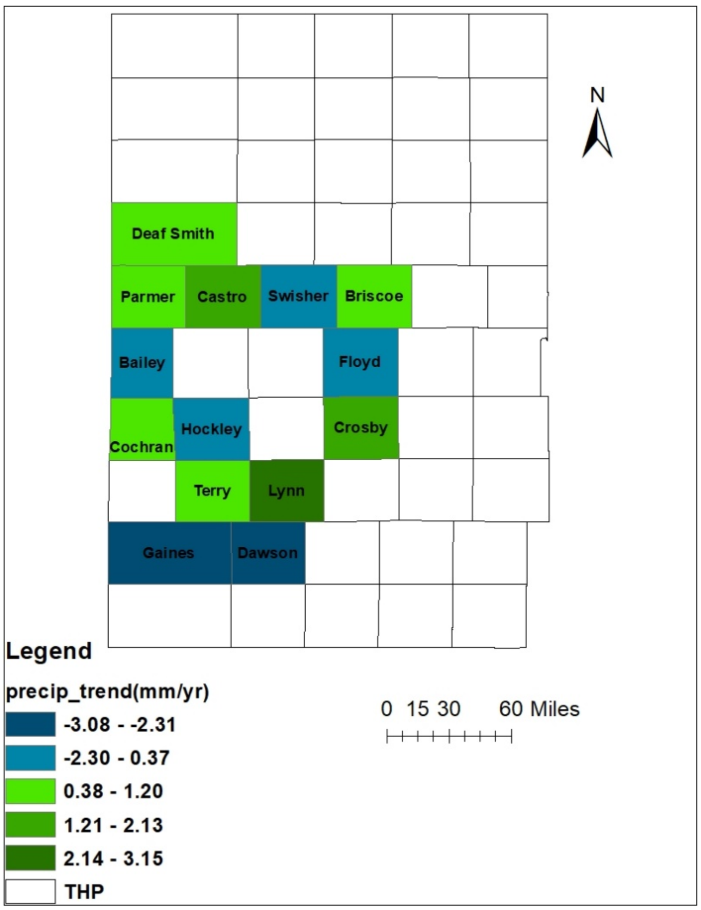

Figure 4.1: Map showing annual precipitation trend

The map shows that Lynn County has the highest positive precipitation trend. Castro and Crosby Counties are the next counties with a higher positive precipitation trend and then Deaf Smith, Parmer, Briscoe, Cochran, and Terry has the lowest positive precipitation trends. Gaines and Dawson Counties have the highest negative precipitation trends, and then Bailey, Hockley, Swisher, and Floyd have the lowest negative precipitation trends.

4.1.2 Spatial Analysis of the Impact of Annual Precipitation Trend on Cotton Yield

In Figure 4.2, the dark green color represents counties with a higher positive correlation between precipitation and cotton yield, and light green colors represent counties with a lower positive correlation between precipitation and cotton yield. Dark blue colors represent counties with a higher negative correlation between precipitation and cotton yield, and light blue colors represent counties with a lower negative correlation between precipitation and cotton yield.

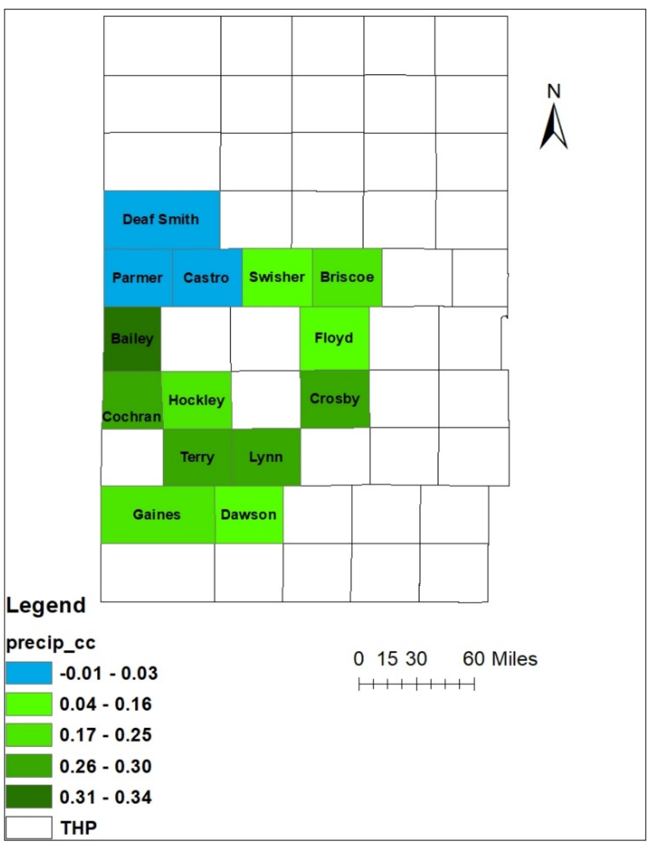

Figure 4.2: Map showing the correlation between annual precipitation and cotton yield

The map shows that Bailey County has the highest positive correlation between precipitation and cotton yield, Cochran, Terry, Lynn, and Crosby Counties are the next counties with a higher positive correlation between precipitation and cotton yield. Gaines, Hockley, and Briscoe counties have a lower negative correlation between precipitation and cotton yield, and then Floyd, Swisher, and Dawson counties have the lowest negative correlation between precipitation and cotton yield.

4.1.3 Spatial Analysis of Annual Mean Air Temperature Trend

In Figure 4.3, the dark green color represents counties with higher positive air temperature trends, and light green colors represent counties with lower positive air temperature trends. Dark blue colors represent counties with higher negative air temperature trends, and light blue colors represent counties with lower negative air temperature trends.

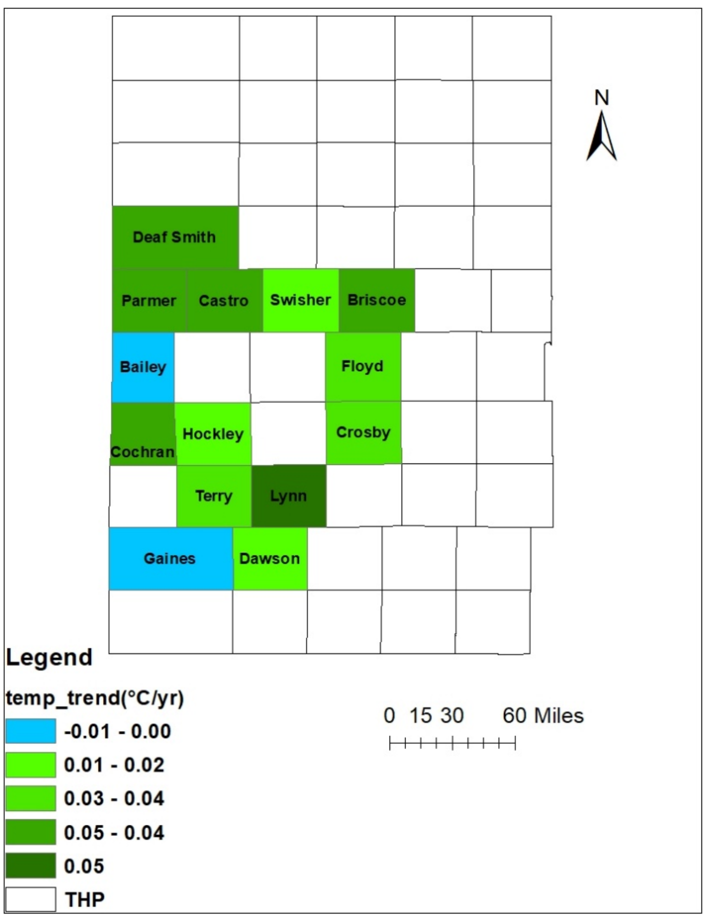

Figure 4.3: Map showing annual mean temperature trend

From the map, Lynn County has the highest positive trend for air temperature, Deaf Smith, Parmer, Castro, Briscoe, and Cochran counties have higher positive air temperature trends. Terry, Floyd, and Crosby counties have low positive air temperature trends, while Swisher, Hockley, and Dawson counties have the lowest positive air temperature trends. From this map, only Bailey and Gaines counties have negative air temperature trends.

4.1.4 Spatial Analysis of the Impact of Annual Mean Air Temperature Trend on Cotton Yield

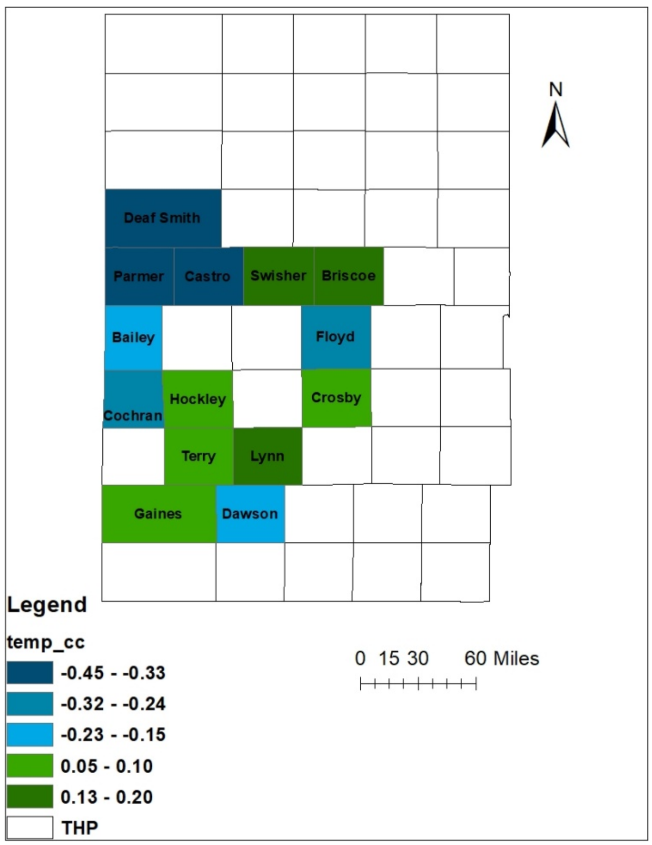

Figure 4.4: Map showing the correlation between annual mean temperature and cotton yield

In Figure 4.4, the dark green color represents counties with a higher positive correlation between mean temperature and cotton yield, and light green colors represent counties with a lower positive correlation between mean temperature and cotton yield. Dark blue colors represent counties with a higher negative correlation between mean temperature and cotton yield, and light blue colors represent counties with a lower negative correlation between mean temperature and cotton yield. According to Figure 4.4, Lynn, Swisher, and Briscoe counties have the highest positive correlation between mean air temperature and cotton yield. Terry, Gaines, Hockley, and lower positive correlation between mean air temperature and cotton yield. Deaf Smith, Parmer, and Castro Counties have the highest negative correlation between mean air temperature and cotton yield. Floyd and Cochran counties have a lower negative correlation between air temperature and cotton yield. Lastly, Bailey and Dawson counties have the lowest negative correlation between mean air temperature and cotton yield.

4.2 Growing Season Precipitation and Temperature Trends and Their Correlation with Cotton Yield

Table 4.2 list precipitation and temperature trends for the growing season of cotton and how the yield is affected by precipitation and temperature. The results on precipitation and temperature trends from the table were obtained using the trend analysis method. The results related to the impacts of precipitation and temperature on cotton yield were obtained using the correlation analysis method.

Based on Table 4.2, Bailey County, the precipitation trend is 0.1225 ($p>0.05$), and the temperature trend is -0.0049 ($p>0.05$). Both temperature and precipitation have insignificant trends during the cotton growing season. The correlation between precipitation and cotton yield is 0.3774 ($p>0.05$), and the correlation between temperature and cotton yield is -0.1317 ($p>0.05$). Therefore, both precipitation and temperature in the growing season have a low or insignificant impact on cotton yield for Bailey County.

In Briscoe County, the precipitation trend is 0.7861 ($p>0.05$), and the temperature trend is 0.0409 ($p<0.01$). In this county, precipitation has an insignificant trend, but the trend for temperature is very significant. Correlation between precipitation and cotton yield is 0.2191 (p>0.05), and that of temperature is 0.1334 (p>0.05). Precipitation and temperature in the growing season have a low or insignificant impact on cotton yield for Briscoe County.

Table 4.2: Growing season precipitation and temperature trends and their correlation with cotton yield

County	Precipitation trend (mm/year)	Correlation between P&CY	Temperature trend (°C/year)	Correlation between T&CY
Bailey	0.1225	0.3774	-0.0049	-0.1317
Briscoe	0.7861	0.2191	0.0409**	0.1334
Castro	1.1525	-0.0633	0.0363 **	0.4501 **
Cochran	0.3601	0.1973	0.0376 **	0.1350
Crosby	2.0730	0.3000	0.0326	-0.0591
Dawson	-2.1021	0.0983	0.0138	-0.0658
Deaf smith	1.3980	-0.0652	0.0320 *	0.2583
Floyd	0.0145	0.1024	0.0158	-0.0064
Gaines	-2.6883	0.1470	0.0081	-0.2826
Hockley	0.6977	0.2299	0.0119	-0.1201
Lynn	2.9109	0.2581	0.0437 *	0.0873
Parmer	1.7170	-0.0386	0.0437 **	0.3368
Swisher	-0.0234	-0.0427	0.0157	0.1756
Terry	0.5009	0.0296	0.0373 **	-0.0843

**p<0.01, very significant; *p<0.05, significant; p>0.05 insignificant

In Castro County, the precipitation trend is 1.1525 (p>0.05), and the temperature trend is 0.0363 (p<0.01). Correlation between precipitation and cotton yield for this county is -0.0633 (p>0.05), the temperature has a correlation of 0.4501 (p<0.01). Castro, just like Briscoe County, has an insignificant trend of the precipitation in the growing season, but the temperature trend in the growing season is very significant. Precipitation has a weak impact on cotton yield, but the temperature has a strong and significant impact on cotton yield.

In Cochran County, precipitation trend is 0.3601 (p>0.05) and temperature trend is 0.0376 (p<0.01). Precipitation has an insignificant trend, but the trend for temperature is very significant. Correlation between precipitation and cotton yield is 0.1973 (p>0.05), and the correlation between temperature and cotton yield is 0.1350 (p>0.05). Both precipitation and temperature in the growing season have an insignificant impact on cotton yield in this county.

Crosby County has a precipitation trend of 2.073 (p>0.05) and a temperature trend of 0.0326 (p>0.05). Precipitation and temperature have insignificant trends. Correlation between precipitation and cotton yield is 0.3000 (p>0.05); therefore, precipitation has an insignificant impact on cotton yield. The temperature has a correlation of -0.0591 (p>0.05) with cotton yield, and its impact is insignificant.

Precipitation trend for Dawson County is -2.1021 (p>0.05), and the temperature trend is 0.0138 (p>0.05); both precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.0983 (p>0.05); also, the correlation between temperature and cotton yield is -0.0658 (p>0.05). Both precipitation and temperature in the growing season have an insignificant impact on cotton yield for Dawson County.

Deaf Smith County has a precipitation trend of 1.398 (p>0.05) and a temperature trend of 0.0320 (p<0.05), the precipitation trend for this county is insignificant while the temperature trend is significant. The correlation between precipitation and cotton yield is -0.0652 (p>0.05), and also the correlation between temperature and cotton yield is 0.2583 (p>0.05). There is an insignificant impact of precipitation and temperature on cotton yield in the growing season for this county.

In Floyd County, the precipitation trend in the growing season is 0.0145 (p>0.05), and the temperature trend is 0.0158 (p>0.05). Both precipitation and temperature have insignificant trends. The correlation between precipitation and cotton yield is 0.1024 (p>0.05), and the correlation between temperature and cotton yield is -0.0064 (p>0.05). Precipitation and temperature have an insignificant impact on cotton yield.

The precipitation trend for Gaines County is -2.6883 (p>0.05), and the temperature trend is 0.0081 (p>0.05). There is an insignificant trend for both precipitation and temperature in the growing season for this county. The correlation between precipitation and cotton yield is 0.1470 (p>0.05), and the correlation between temperature and cotton yield is -0.2826 (p>0.05). Both precipitation and temperature have an insignificant impact on cotton yield

Hockley County shows a precipitation trend of 0.6977 (p>0.05), and the temperature trend is 0.0119 (p>0.05). There is an insignificant trend for both temperature and precipitation. The correlation between cotton yield and precipitation is 0.2299 (p>0.05), and the correlation between temperature and cotton yield is -0.1201 (p>0.05). Both precipitation and temperature have an insignificant impact on cotton yield in the growing season.

Lynn County has a precipitation trend of 2.9109 (p>0.05), and the temperature trend is 0.0437 (p<0.05). The precipitation trend for the county is insignificant, while the temperature trend is significant. The correlation between precipitation and cotton yield is 0.2581 (p>0.05), and the correlation between temperature and cotton yield is 0.0873 (p>0.05). Both precipitation and cotton yield has an insignificant impact on cotton yield for this county in the growing season.

Parmer County has a precipitation trend of 1.7170 (p>0.05), and the temperature trend 0.0437 (p<0.01). The precipitation trend is insignificant, while the temperature trend is very significant. The correlation between precipitation and cotton yield is -0.0386 (p>0.05), and the correlation between temperature and cotton yield is 0.3368 (p>0.05). During the growing season in this county, precipitation and temperature have an insignificant impact on cotton yield.

There is an insignificant precipitation trend of -0.0234 (p>0.05) for Swisher county and a temperature trend of 0.0157 (p>0.05), which is also insignificant. The correlation between precipitation and cotton yield is -0.0427 (p>0.05), and the correlation between temperature and cotton yield is 0.1756 (p>0.05). In this county, both precipitation and temperature have an insignificant impact on cotton yield.

Terry County has a precipitation trend of 0.5009 ($p>0.05$) and a temperature trend of 0.0373 ($p<0.01$). The temperature trend for this county is very significant, while the precipitation trend is not significant. The correlation between precipitation and cotton yield is 0.0296 ($p>0.05$), and the correlation between temperature and cotton yield is -0.0843 ($p>0.05$). The precipitation and temperature in the growing season in this county both have an insignificant impact on cotton yield.

4.2.1 Spatial Analysis of the Growing Season Precipitation Trend

The growing season precipitation trends are shown in Figure 4.5. The dark green color represents counties with higher positive precipitation trends, and light green colors represent counties with lower positive precipitation trends. Dark blue colors represent counties with higher negative precipitation trends, and light blue colors represent counties with lower negative precipitation trends.

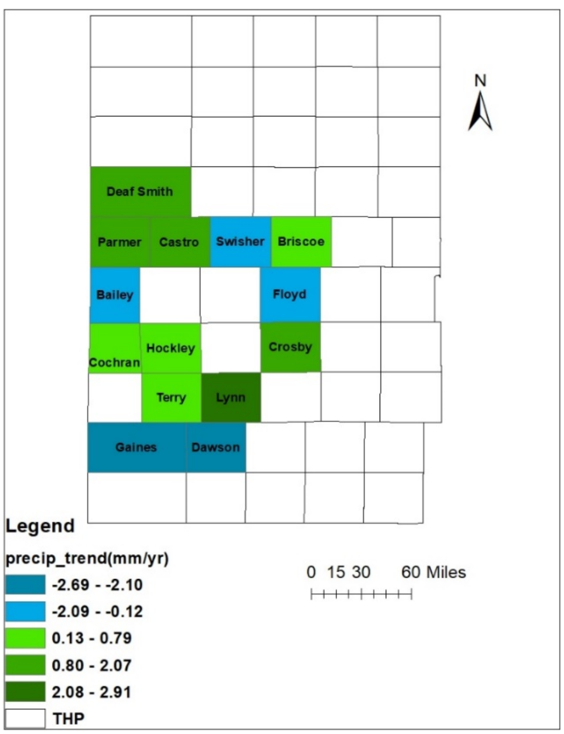

Figure 4.5: Map showing growing season precipitation trend

Figure 4.5 shows that in the growing season, Lynn county has the highest positive precipitation trend, Castro, Crosby, Parmer, and Deaf Smith counties are the next counties with a higher positive precipitation trend and then, Briscoe, Cochran, Terry, and Hockley have the lowest positive precipitation trends. Gaines and Dawson counties have the highest negative precipitation trends, and then Bailey, Swisher, and Floyd have the lowest negative precipitation trends.

4.2.2 Spatial Analysis of the Impact of Growing Season Precipitation on Cotton Yield

In Figure 4.6, the dark green color represents counties with a higher positive correlation between precipitation and cotton yield, and light green colors represent counties with a lower positive correlation between precipitation and cotton yield. Dark blue colors represent counties with a higher negative correlation between precipitation and cotton yield, and light blue colors represent counties with a lower negative correlation between precipitation and cotton yield.

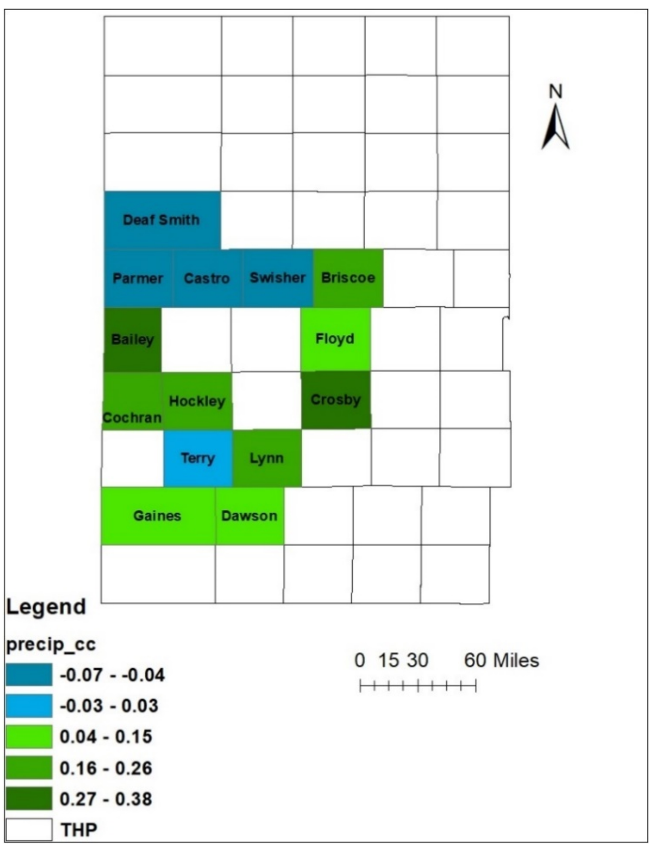

Figure 4.6: Map showing the correlation between growing season precipitation and cotton yield

The map shows that Bailey and Crosby counties have the highest positive correlation between total precipitation and cotton yield. Cochran, Hockley, Lynn, and Briscoe Counties are the next counties with a higher positive correlation between total precipitation and cotton yield. Gaines, Dawson, and Floyd counties have a lower positive correlation between total precipitation and cotton yield. Deaf Smith, Parmer, Castro, and Swisher counties have a higher negative correlation between precipitation and cotton yield, and then Terry County has the lowest negative correlation between precipitation and cotton yield.

4.2.3 Spatial Analysis of Growing Season Mean Air Temperature Trends

In Figure 4.7, the dark green color represents counties with higher positive air temperature trends, and light green colors represent counties with lower positive air temperature trends. Dark blue colors represent counties with higher negative air temperature trends, and light blue colors represent counties with lower negative air temperature trends.

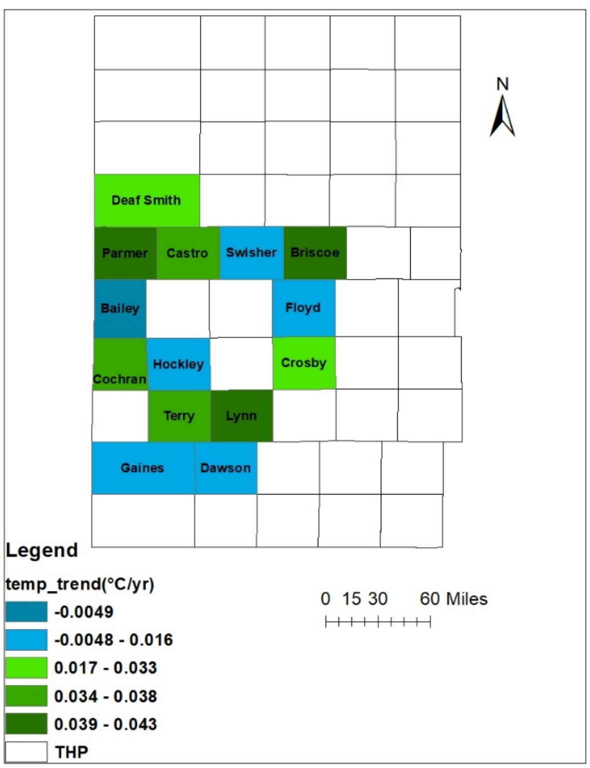

Figure 4.7: Map showing growing season mean temperature trend

According to Figure 4.7, Lynn, Parmer, and Briscoe Counties have the highest positive trend for air temperature. Castro, Terry, and Cochran counties have higher positive air temperature trends. Deaf Smith and Crosby counties have low positive air temperature trends. Bailey County has the highest negative air temperature trend, and Swisher, Hockley, Dawson, Gaines, and Floyd counties have the lowest negative air temperature trends.

4.2.4 Spatial Analysis of the Correlation between Growing Season Mean Air Temperature and Cotton Yield

In Figure 4.8, the dark green color represents counties with a higher positive correlation between mean air temperature and cotton yield, and light green colors represent counties with a lower positive correlation between mean air temperature and cotton yield. Dark blue colors represent counties with a higher negative correlation between mean air temperature and cotton yield, and light blue colors represent counties with a lower negative correlation between mean temperature and cotton yield.

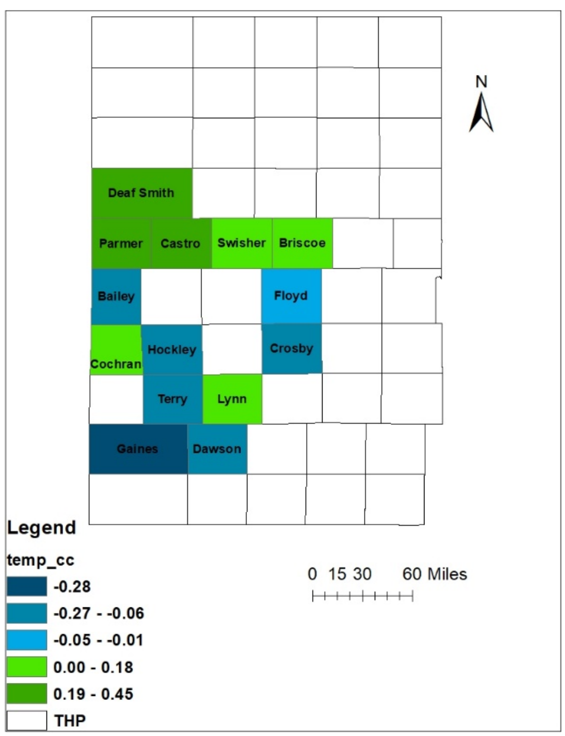

Figure 4.8: Map showing the correlation between growing season mean temperature and cotton yield

According to Figure 4.8, Deaf Smith, Parmer, and Castro counties have the highest positive correlation between mean air temperature and cotton yield. Lynn, Swisher, Cochran, and Briscoe counties have a lower positive correlation between mean air temperature and cotton yield. Gaines County has the highest negative correlation between mean air temperature and cotton yield. Bailey, Hockley, Terry, Dawson, and Crosby counties have a lower negative correlation between air temperature and cotton yield, and lastly, Floyd County has the lowest negative correlation between mean air temperature and cotton yield.

4.3 Correlations between Cotton Yield and Temperature and Precipitation at Different Cotton Growth Stages

There are six different stages of cotton growth, namely the seedling stage, the leaf development stage, the flowering stage, the boll development stage, the boll opening stage, and lastly, the harvest stage. The growing season climate has been analyzed as a whole to show how it changed in the past 30 years. Precipitation in the growing season shows an insignificant impact on cotton yield for all the counties, while temperature shows a very significant impact on cotton yield for one county (i.e., Castro County), while in all other counties growing season air temperature has an insignificant impact on cotton yield. It is, therefore, important to assess the impacts of precipitation and air temperature at different growth stages on cotton yield.

Aside from the six stages of cotton growth, this research also analyzed precipitation 30 days prior to the planting of cotton (i.e., April 1st to April 30th) to evaluate its impact on cotton yield. The research calls this stage the pre-planting stage.

4.3.1 Pre-Planting Stage Precipitation Trends and Their Correlation with Cotton Yield

Table 4.3 lists pre-planting stage precipitation trends and their correlation with cotton yield. The results of the pre-planting stage precipitation trend were obtained using the trend analysis method and the impacts of the pre-planting stage precipitation on cotton yield were evaluated using correlation analysis.

Table 4.3: Pre-planting stage precipitation and temperature trends and their correlation with cotton yield

County	Precipitation trend (mm/year)	Correlation between P&C
Bailey	-0.0070	0.0531
Briscoe	0.0006	0.2045
Castro	0.0010	0.2945
Cochran	0.0017	0.2393
Crosby	-0.0026	0.1569
Dawson	0.0015	0.1762
Deaf Smith	-0.0029	0.2235
Floyd	0.0033	0.1979
Gaines	0.0075	0.2599
Hockley	0.0027	0.2489
Lynn	0.0009	0.1233
Parmer	-0.0015	0.1213
Swisher	0.0048	0.2346
Terry	0.0005	0.1253

**p<0.01, very significant; *p<0.05, significant; p>0.05 insignificant.

In Table 4.3, there is an insignificant precipitation trend for all counties, and the correlation between precipitation and cotton yield is insignificant for all counties in the pre-planting stage. Precipitation in the pre-planting stage is therefore not important or insignificant to cotton yield.

4.3.2 Seedling Stage Precipitation and Temperature Trends and Their Correlation with Cotton Yield

Table 4.4 lists the precipitation and temperature trends and how cotton yield is affected by precipitation and temperature for the seedling stage of cotton growth. The results on precipitation and temperature trends were obtained using trend analysis and the impacts of precipitation and temperature on cotton yield were evaluated using correlation analysis.

Cotton farmers plant in the early days of May, mostly on the first day of May. After planting, the seedling stage begins from the 4th to the 9th day. In Table 4.4, the seedling stage has insignificant precipitation and temperature trends and also precipitation and temperature have an insignificant impact on cotton yield since the correlation between precipitation and cotton yield, as well as temperature and cotton yield all not significant

Table 4.4: Seedling stage precipitation and temperature trends and their correlation with cotton yield

County	Precip Trend (mm/year)	Corr between P&CY	Temp Trend (°C/year)	Corr between T&CY	Avg Max Temp Trend	Corr between ATmax & CY	Avg Min Temp Trend	Corr between Atmin & CY
Bailey	0.0036	-0.1623	-0.0072	-0.2798	0.0352	-0.2798	-0.0710	-0.1871
Briscoe	-0.0051	-0.1467	2.6137	-0.0285	0.0824	-0.0285	-0.0763	-0.0168
Castro	-0.1498	-0.0289	0.0009	0.0125	0.0837	0.0125	-0.0230	0.0078
Cochran	0.1652	0.1600	0.0027	-0.1265	0.0850	-0.1265	-0.0152	-0.0850
Crosby	0.4692	-0.0549	-0.0004	-0.1025	0.0529	-0.1025	0.0038	-0.0736
Dawson	0.0037	-0.0259	-0.0005	-0.3211	0.0246	-0.3211	-0.0104	-0.2455
Deaf Smith	-0.0013	-0.0736	0.0047	-0.0912	0.0009	-0.0912	-0.0305	-0.0584
Floyd	0.0029	0.0085	-0.0004	-0.0881	0.0006	-0.0881	0.0029	-0.0585
Gaines	0.0024	-0.0127	-0.0050	-0.2325	0.0188	-0.2325	-0.0111	-0.1718
Hockley	0.0042	-0.0881	-0.0196	-0.1318	0.0390	0.0870	0.0208	0.0434
Lynn	0.0011	0.1721	0.0010	-0.2160	0.0467	-0.2160	-0.0068	-0.1507
Parmer	0.0008	0.0296	0.0035	-0.0810	0.0009	-0.0810	-0.0148	-0.0501
Swisher	-0.0252	-0.1060	-0.0239	0.0274	0.0027	-0.0922	0.0021	0.2265
Terry	0.0017	0.0652	0.0016	-0.2307	0.0007	-0.2307	-0.0082	-0.1727

**$p<0.01$, very significant; *$p<0.05$, significant; $p>0.05$ insignificant.

4.3.3 Leaf Development Stage Precipitation and Temperature Trends and Their Correlation with Cotton Yield

Table 4.5 lists the precipitation and temperature trends for the leaf development stage of cotton growth and how cotton yield is affected by precipitation and temperature. The results on precipitation and temperature trends were obtained using trend analysis and the impacts of precipitation and temperature on cotton yield were evaluated using correlation analysis.

Table 4.5: Leaf development stage precipitation and temperature trends and their correlation with cotton yield

County	Precip Trend (mm/year)	Corr between P&CY	Temp Trend (°C/year)	Corr between T&CY	Avg Max Temp Trend	Corr between ATmax & CY	Avg Min Temp Trend	Corr between Atmin & CY
Bailey	0.0230	-0.0007	-0.0151	0.0525	0.0264	0.0525	0.0011	0.0233
Briscoe	-0.0006	0.0244	0.0060	0.0084	0.0472	0.0081	0.0014	0.0038
Castro	-0.0044	-0.1575	-0.0239	0.0274	0.0388	0.0274	0.0011	0.0137
Cochran	-0.0012	0.1258	-0.0209	-0.1804	0.0120	-0.1804	0.0013	-0.0818
Crosby	0.0518	0.0309	-0.0132	-0.1776	0.0159	-0.1776	0.0008	-0.0781
Dawson	-0.0010	-0.1060	-0.0302	-0.0369	0.0097	-0.0369	0.0591	-0.0189
Deaf Smith	0.0030	-0.3092	-0.0170	0.1545	0.0215	0.1545	0.0009	0.0815
Floyd	0.0006	0.0944	-0.0196	-0.1318	0.0197	-0.1318	0.0007	-0.0620
Gaines	-0.0011	0.1356	-0.0005	-0.141	-0.0005	-0.1410	0.0398	-0.0751
Hockley	-0.0007	0.1704	0.0263	-0.2563	0.0472	-0.1360	0.0610	-0.1222
Lynn	-0.0008	0.1576	-0.0044	-0.1947	0.0221	-0.1947	0.0009	-0.0941
Parmer	-0.0031	-0.4536**	-0.0171	0.1991	0.0114	0.1991	0.0009	0.1974
Swisher	-0.0008	0.0332	0.0401	-0.2767	0.0346	-0.3223	0.0009	-0.0433
Terry	-0.0014	0.1959	-0.0151	-0.0809	0.0264	-0.1302	0.0011	-0.0788

**p<0.01, very significant; *p<0.05, significant; p>0.05 insignificant.

The leaf development stage starts from 20 to 27 days after planting. In Table 4.5, the precipitation and temperature trends are all insignificant. The correlation between precipitation and cotton yield is insignificant for 13 counties except for Parmer county, which shows a correlation of -0.4536 ($p<0.01$): this indicates that in Parmer County, precipitation has a very significant impact on cotton yield. Also, the correlation between temperature and cotton yield is insignificant for all of the counties.

4.3.4 Flowering Stage Precipitation and Temperature Trends and Their Correlation with Cotton Yield

Table 4.6 lists the precipitation and temperature trends for the flowering stage of cotton growth and how the yield is affected by precipitation and temperature. The results on precipitation and temperature trends were obtained using trend analysis and the impacts of precipitation and temperature on cotton yield were evaluated using correlation analysis. . The flowering stage is the third stage of cotton growth, and it starts 60 to 70 days after planting.

According to Table 4.6, Bailey County has a precipitation trend of 0.0198 (p>0.05) and a temperature trend of 0.0104 (p>0.05). Both precipitation and temperature trends are insignificant in the flowering stage. The correlation between precipitation and cotton yield is 0.2489 (p>0.05), and the correlation between temperature and cotton yield is 0.0871 (p>0.05). Both precipitation and temperature have an insignificant impact on cotton yield in the flowering stage. The average maximum temperature has a trend of 0.0032 (p>0.05), and the average minimum temperature has a trend of -0.0006 (p>0.05). Both trends are insignificant at the flowering stage, and they have an insignificant impact on cotton yield.

In Briscoe County, the precipitation trend is -0.0002 (p>0.05) and the temperature is 0.045 (p>0.05). There is an insignificant trend for both precipitation and temperature in the flowering stage. The correlation between precipitation and cotton yield is 0.1448 (p>0.05), and the correlation between temperature and cotton yield is 0.0423 (p>0.05). There is an insignificant impact on cotton yield from precipitation and temperature. The average maximum temperature and average minimum temperature trends are both insignificant, and they have an insignificant impact on cotton yield for this stage.

The precipitation trend for Castro County is 0.0092 (p>0.05), and the temperature trend is 0.0006 (p<0.01). The temperature trend for this is very significant, but the precipitation trend is insignificant. The correlation between precipitation and cotton yield is -0.1398 (p>0.05), and the correlation between temperature and cotton yield is 0.4029 (p<0.05). Precipitation has an insignificant impact on cotton yield at the flowering stage, while temperature has a significant impact on yield. The average maximum temperature and average minimum temperature trends are both insignificant, and they have an insignificant impact on cotton yield.

Table 4.6: Flowering stage precipitation and temperature trends and their correlation with cotton yield

County	Precip Trend (mm/year)	Corr between P&CY	Temp Trend (°C/year)	Corr between T&CY	Avg Max Temp Trend	Corr between ATmax & CY	Avg Min Temp Trend	Corr between Atmin & CY
Bailey	0.0198	0.2489	0.0104	0.0871	0.0032	0.0236	-0.0006	-0.3122
Briscoe	-0.0002	0.1448	0.0450	0.0423	0.0507	-0.0235	0.0006	0.0532
Castro	0.0092	-0.1398	0.0006**	0.4029*	0.0390	0.0870	0.0208	0.0434
Cochran	-0.0021	-0.0863	0.0620**	0.1717	0.0399	0.0264	0.0585	-0.1018
Crosby	0.0016	0.3575*	0.0399	-0.0943	0.0049	-0.2250	0.0548	-0.1269
Dawson	-0.0013	0.0926	0.0128	-0.0629	-0.0011	-0.2848	0.0145	-0.0633
Deaf Smith	-0.0012	-0.1931	0.0006**	0.3604*	0.0027	-0.0922	0.0012	0.2265
Floyd	-0.0009	-0.0099	0.0007	0.2345	-0.0059	-0.1497	0.0026	0.164
Gaines	0.0020	0.2892	0.0274*	0.1687	0.0336	-0.1660	0.0369	-0.1059
Hockley	0.0007	0.1408	0.0275	-0.0519	-0.0031	-0.2562	0.0376	-0.1614
Lynn	-0.0004	0.0687	0.0548*	0.1295	0.0436	0.0831	0.0312	0.0217
Parmer	0.0045	-0.1319	0.0577**	0.3165	0.0341	-0.0008	0.0236	0.1625
Swisher	-0.0012	-0.2395	0.0387	0.3165	0.0081	0.0222	0.0137	-0.0636
Terry	0.0044	0.1282	0.0597**	0.0194	0.0560	-0.1721	0.0006	-0.2032

**$p<0.01$, very significant; *$p<0.05$, significant; $p>0.05$ insignificant.

Cochran County has a precipitation trend of -0.0021 ($p>0.05$) and a temperature trend of 0.0620 ($p<0.01$). The precipitation trend is insignificant, and the temperature trend is very significant. The correlation between precipitation and cotton yield is -0.0863 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1717 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature both have insignificant trends for this county at the flowering stage, and they have an insignificant impact on cotton yield.

The precipitation trend for Crosby County is 0.0016 ($p>0.05$), and the temperature trend is 0.0399 ($p>0.05$). Both precipitation and temperature trends have insignificant trends for this county in the flowering stage. The correlation between precipitation and cotton yield is 0.3575 ($p<0.05$), and the correlation between temperature and cotton yield is -0.0943 ($p>0.05$). Precipitation for this county has a significant impact on cotton yield, but the temperature has an insignificant impact on cotton yield. Both average maximum temperature and average minimum temperature have insignificant trends, and also they have an insignificant impact on cotton yield.

Dawson County has a precipitation trend of -0.0013 ($p>0.05$) and a temperature trend of 0.0128 ($p>0.05$). The precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.0926 ($p>0.05$), and the correlation between temperature and cotton yield is -0.0629 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature trends are not significant, and they have an insignificant impact on cotton yield.

There is a precipitation trend of -0.0012 ($p> 0.05$) in Deaf Smith County, the temperature trend is 0.0006 ($p<0.01$). The precipitation trend for this county in the flowering stage is insignificant, and but the temperature trend is very significant. The correlation between precipitation and cotton yield is -0.1931 ($p>0.05$), and the correlation between temperature and cotton yield is 0.3604 ($p<0.05$). There is an insignificant impact of precipitation on cotton yield, but a significant impact of temperature on cotton yield in the flowering stage for this county. The average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

In Floyd County, there is a precipitation trend of -0.0009 ($p>0.05$), and the temperature trend is 0.0007 ($p>0.05$). Both precipitation and temperature trends are insignificant for this county in the flowering stage. The correlation between precipitation and cotton yield is -0.0099 ($p>0.05$) and the correlation between temperature and cotton yield is 0.2345 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature have insignificant trends and an insignificant impact on cotton yield.

The precipitation trend for Gaines County is 0.0020 ($p>0.05$), and the temperature trend is 0.0274 ($p<0.05$). Precipitation has an insignificant trend for this county, but the temperature has a significant trend. The correlation between precipitation and cotton yield is 0.2892 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1687 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

In Hockley County, the precipitation trend is 0.0007 ($p>0.05$), and the temperature trend is 0.0275 ($p>0.05$). The precipitation and temperature trends are insignificant for this county. The correlation between precipitation and cotton yield is 0.1408 ($p>0.05$), and the correlation between temperature and cotton yield is -0.0519 ($p>0.05$) there is an insignificant impact of precipitation and temperature on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

Lynn County has a precipitation trend of -0.0004 ($p>0.05$), and the temperature trend is 0.0548 ($p<0.05$). The precipitation trend for this county is insignificant, but the temperature trend is significant. The correlation between precipitation and cotton yield is 0.0687 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1295 ($p>0.05$). There is an insignificant impact on cotton yield from precipitation and temperature. Average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

There is a precipitation trend of 0.0045 ($p>0.05$) in Parmer County and a temperature trend of 0.0577 ($p<0.01$). The temperature trend for this county is very significant, while the precipitation trend is insignificant. The correlation between precipitation and cotton yield is -0.1319 ($p>0.05$), and the correlation between temperature and cotton yield is 0.3165 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

In Swisher County, the precipitation trend is -0.0012 ($p>0.05$), and the temperature trend is 0.0387 ($p>0.05$). Both precipitation and temperature trends are insignificant for this county. The correlation between precipitation and cotton yield is -0.2395 ($p>0.05$), and the correlation between temperature and cotton yield is 0.3165 ($p>0.05$). There is an insignificant impact of precipitation and temperature on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

Terry county has a precipitation trend of 0.0044 ($p>0.05$) and a temperature trend of 0.0597 ($p<0.01$). The temperature trend for this county is very significant, but the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.1282 ($p>0.05$), and the correlation between temperature and cotton yield is 0.0194 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. Also, the average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

4.3.5 Boll Development Stage Precipitation and Temperature Trends and Their Correlation with Cotton Yield

Table 4.7, lists the precipitation and temperature trends as well as how they affect cotton yield in the boll development stage. The results on precipitation and temperature trends were obtained using trend analysis and the impacts of precipitation and temperature on cotton yield were evaluated using correlation analysis. The boll development stage begins from 70 to 100 days after planting.

Table 4.7: Boll development stage precipitation and temperature trends and their correlation with cotton yield

County	Precip Trend (mm/year)	Corr between P&CY	Temp Trend (°C/year)	Corr between T&CY	Avg Max Temp Trend	Corr between ATmax & CY	Avg Min Temp Trend	Corr between Atmin & CY
Bailey	0.0008	0.4124	0.0074	-0.1917	-0.0016	-0.3055	0.0119	-0.2104
Briscoe	0.0016	0.2719	0.0377	0.0604	0.0008**	0.0895	0.0009*	0.0567
Castro	0.0019	0.0936	0.0408**	0.3842*	0.0310	0.0934	0.0391	-0.0259
Cochran	0.0006	0.3119	0.0459**	0.1783	0.0498	-0.1028	0.0549	-0.1538
Crosby	-0.0014	0.1695	0.0446**	0.0971	0.0523	-0.1312	0.0524	-0.2010
Dawson	-0.0005	0.194	0.0058	0.1101	0.0444	-0.0955	0.0087	-0.0770
Deaf Smith	0.0016	0.2506	0.0410**	0.1470	0.0384	-0.0620	0.0583	0.0293
Floyd	0.1226	0.1354	0.0242	0.0777	0.0206	-0.0932	0.0623	-0.0220
Gaines	-0.0002	0.1448	0.0450	0.0423	0.0507	-0.0235	0.0006	0.0532
Hockley	-0.0023	0.1337	0.0216	0.0222	0.0003	-0.2812	0.0146	-0.1786
Lynn	0.0025	0.1745	0.0570**	0.2683	0.0606*	0.0335	0.0572	0.0149
Parmer	0.0018	0.2126	0.0589**	0.1360	0.0458	-0.0002	0.0336	-0.0404
Swisher	0.0020	0.2892	0.0274*	0.1687	0.0336	-0.1660	0.0369	-0.1059
Terry	0.0012	0.2080	0.0419**	-0.0027	0.0501	-0.1813	0.0006	-0.1251

**p<0.01, very significant; *p<0.05, significant; p>0.05 insignificant.

In Table 4.7, Bailey County has a precipitation trend of 0.0008 ($p>0.05$) and a temperature trend of 0.0074 ($p>0.05$). Precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.4124 ($p>0.05$), and the correlation between temperature and cotton yield is -0.1917 ($p>0.05$). There is an insignificant impact on cotton yield from precipitation and temperature. Also, the average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

In Briscoe County, the precipitation trend is 0.0016 ($p>0.05$), and the temperature trend is 0.0377 ($p>0.05$). The precipitation and temperature trends are both insignificant. The correlation between temperature and cotton yield is 0.0604 ($p>0.05$), and the correlation between precipitation and cotton yield is 0.2719 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. Also, in this county, the average maximum temperature has a very significant trend of 0.0008 ($p<0.01$), but the average minimum temperature has a significant trend of 0.0009 ($p<0.05$). Average maximum and minimum temperatures have an insignificant impact on cotton yield.

The precipitation trend for Castro County is 0.0019 ($p>0.05$), and the temperature trend is 0.0408 ($p<0.01$). The temperature trend for this is very significant, but the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.0936($p>0.05$), and the correlation between temperature and cotton yield is 0.3842 ($p<0.05$). Precipitation has an insignificant impact on cotton yield at the boll development stage, while temperature has a significant impact on yield. The average maximum temperature and average minimum temperature trends are both insignificant, and they have an insignificant impact on cotton yield.

Cochran County has a precipitation trend of 0.0006 ($p>0.05$) and temperature trend of 0.0459 ($p<0.01$). The precipitation trend is insignificant, but the temperature trend is very significant. The correlation between precipitation and cotton yield is 0.3119 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1783($p>0.05$). The precipitation and temperature have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature have insignificant trends for this county at the flowering stage, and they have an insignificant impact on cotton yield.

The precipitation trend for Crosby County is -0.0014 ($p>0.05$), and the temperature trend is 0.0446($p<0.01$). The precipitation trend is insignificant, but the temperature trend is very significant for this county in the boll development stage. The correlation between precipitation and cotton yield is 0.1695 ($p>0.05$), and the correlation between temperature and cotton yield is 0.0971 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

Dawson County has a precipitation trend of -0.0005 ($p>0.05$) and a temperature trend of 0.0058 ($p>0.05$). The precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.194 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1101 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature trends are not significant, and they have an insignificant impact on cotton yield.

In Deaf Smith County, there is a precipitation trend of 0.0016 ($p> 0.05$). The temperature trend is 0.0410 ($p<0.01$). The precipitation trend for this county in the boll development stage is insignificant, and but the temperature trend is very significant. The correlation between precipitation and cotton yield is 0.2506 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1470 ($p>0.05$). There is an insignificant impact of precipitation and temperature on cotton yield. The average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

In Floyd County, there is a precipitation trend of 0.1226 ($p>0.05$), and the temperature trend is 0.0242 ($p>0.05$). Precipitation and temperature trends are insignificant for this county in the boll development stage. The correlation between precipitation and cotton yield is 0.1354 ($p>0.05$), and the correlation between temperature and cotton yield is 0.0777 ($p>0.05$). Precipitation and temperature both have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature have an insignificant trend and also an insignificant impact on cotton yield.

The precipitation trend for Gaines County is -0.0002 ($p>0.05$), and the temperature trend is 0.0450 ($p>0.05$). Precipitation and temperature have an insignificant trend in this county. The correlation between precipitation and cotton yield is 0.1448 ($p>0.05$), and the correlation between temperature and cotton yield is 0.0423 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

In Hockley County, the precipitation trend is -0.0023 ($p>0.05$), and the temperature trend is 0.0216 ($p>0.05$). The precipitation and temperature trends are insignificant for this county. The correlation between precipitation and cotton yield is 0.1337 ($p>0.05$), and the correlation between temperature and cotton yield is 0.0222 ($p>0.05$). There is an insignificant impact of precipitation and temperature on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

Lynn County has a precipitation trend of 0.0025 ($p>0.05$), and the temperature trend is 0.057 ($p<0.01$). The precipitation trend for this county is insignificant, but the temperature trend is very significant. The correlation between precipitation and cotton yield is 0.1745 ($p>0.05$), and the correlation between temperature and cotton yield is 0.2683 ($p>0.05$). There is an insignificant impact on cotton yield from precipitation and temperature. Also, in this county, the average maximum temperature has a significant trend of 0.0606 ($p<0.01$), but the average minimum temperature trend is insignificant. Average maximum and minimum temperatures have an insignificant impact on cotton yield.

There is a precipitation trend of 0.0018 ($p>0.05$) in Parmer County and a temperature trend of 0.0589 ($p<0.01$). The temperature trend for this county is very significant, while the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.2126 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1360($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and they also have an insignificant impact on cotton yield.

In Swisher County, the precipitation trend is 0.0020 ($p>0.05$), and the temperature trend is 0.0274 ($p<0.05$). The temperature trend for this county is significant, while the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.2892 ($p>0.05$), and the correlation between temperature and cotton yield is 0.1687 ($p>0.05$). There is an insignificant impact of precipitation and temperature on cotton yield. Average maximum temperature and average minimum temperature have insignificant trends, and also, they have an insignificant impact on cotton yield.

Terry county has a precipitation trend of 0.0012 ($p>0.05$) and a temperature trend of 0.0419 ($p<0.01$). The temperature trend for this county is very significant, but the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.2080 ($p>0.05$), and the correlation between temperature and cotton yield is -0.0027 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield. Also, the average maximum temperature and average minimum temperature have insignificant trends, and they have an insignificant impact on cotton yield.

4.3.6 Boll Opening Stage Precipitation and Temperature Trends and Their Correlation with Cotton Yield

Table 4.8 lists precipitation and temperature trends for the boll opening stage of cotton growth and how the yield is affected by precipitation and temperature. The results on precipitation and temperature trends were obtained using trend analysis and the impacts of precipitation and temperature on cotton yield were evaluated using correlation analysis. The boll opening stage begins from 100 to 130 days after planting.

Table 4.8: Boll opening stage precipitation and temperature trends and their correlation with cotton yield

County	Precip Trend (mm/year)	Corr between P&CY	Temp Trend (°C/year)	Corr between T&CY	Avg Max Temp Trend	Corr between ATmax & CY	Avg Min Temp Trend	Corr between Atmin & CY
Bailey	0.0104	0.2634	-0.0112	-0.3865*	-0.0098	-0.3760	0.0378	-0.2145
Briscoe	0.0006	0.2149	0.0187	-0.2250	0.0538*	-0.0323	0.0012	-0.0030
Castro	0.0016	0.0847	0.0246	0.1176	0.0290	0.1195	0.0610	0.1188
Cochran	0.0656	0.1752	0.0357	-0.1171	0.0323	-0.0188	0.0514	0.0945
Crosby	-0.0007	0.1704	0.0263	-0.2563	0.0472	-0.136	0.0610	-0.1222
Dawson	-0.0009	-0.0727	-0.0161	-0.2294	0.0367	-0.2352	-0.0024	-0.1094
Deaf Smith	0.0009	0.2317	0.0332	-0.0674	0.0250	-0.0525	0.0259	-0.0178
Floyd	0.0040	0.2324	0.0067	-0.1190	0.0131	-0.1399	0.0496	0.0293
Gaines	0.0030	-0.3092	-0.017	0.1545	0.0215	0.1545	0.0009	0.0815
Hockley	-0.0015	-0.064	0.0083	-0.3075	-0.0005	-0.1891	0.0330	0.0093
Lynn	0.0026	0.0853	0.0408	-0.1180	0.0485	-0.0282	0.0010*	0.1313
Parmer	0.0013	0.2655	0.0416	-0.0012	0.0309	0.0451	0.0507	0.0553
Swisher	0.0019	0.4793**	0.0134	-0.2511	0.0269	-0.0754	0.0468	0.0815
Terry	-0.0008	0.0332	0.0401	-0.2767	0.0346	-0.3223	0.0009	-0.0433

**$p<0.01$, very significant; *$p<0.05$, significant; $p>0.05$ insignificant

According to Table 4.8, Bailey County has a precipitation trend of 0.0104 ($p>0.05$) and a temperature trend of -0.0112 ($p>0.05$). Both precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.2634 ($p>0.05$), and the correlation between temperature and cotton yield is -0.3865 ($p<0.05$). There is an insignificant impact on cotton yield from precipitation but a significant impact on cotton yield from temperature. Also, the average maximum temperature and average minimum temperature have insignificant trends, and they also have an insignificant impact on cotton yield.

In Briscoe County, the precipitation trend is 0.0006 ($p>0.05$), and the temperature trend is 0.0187 ($p>0.05$). The precipitation and temperature trends are both insignificant. The correlation between temperature and cotton yield is 0.2149 ($p>0.05$), and the correlation between precipitation and cotton yield is -0.2250 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield. Also, in this county, the average maximum temperature has a significant trend of 0.0538 ($p<0.05$), but the average minimum temperature trend is insignificant. Both average maximum and minimum temperatures have an insignificant impact on cotton yield.

Lynn County has a precipitation trend of 0.0026 ($p>0.05$), and the temperature trend is 0.0408 ($p>0.05$). Both the precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.0853 ($p>0.05$), and the correlation between temperature and cotton yield is -0.1180 ($p>0.05$). There is an insignificant impact on cotton yield from precipitation and temperature. Also, in this county, the average maximum temperature has an insignificant trend, but the average minimum temperature has a significant trend of 0.0010 ($p<0.05$). Both average maximum and minimum temperatures have an insignificant impact on cotton yield.

In Swisher County, the precipitation trend is 0.0020 ($p>0.05$), and the temperature trend is 0.0274 ($p<0.05$). The temperature trend for this county is significant, while the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.4793 ($p<0.01$), and the correlation between temperature and cotton yield is -0.2511 ($p>0.05$). There is a very significant impact of precipitation on cotton yield but an insignificant impact of temperature on cotton yield. Both average maximum temperature and average minimum temperature have insignificant trends, and they also have an insignificant impact on cotton yield.

Aside, the four counties explained above, all the other counties have insignificant precipitation and temperature trends, and also precipitation and temperature have an insignificant impacts on cotton yield since the correlation between precipitation and cotton yield, as well as temperature and cotton yield all not significant.

4.3.7 Harvest Stage Precipitation and Temperature Trends and Their Correlation with Cotton Yield

Table 4.9 lists precipitation and temperature trends for the harvest stage of cotton growth and how the yield is affected by precipitation and temperature. The results on precipitation and temperature trends were obtained using trend analysis and the impacts of precipitation and temperature on cotton yield were evaluated using correlation analysis. The harvest stage begins from 130 to 180 days after planting.

In Table 4.9, Bailey County has a precipitation trend of 0.0007 ($p>0.05$) and a temperature trend of 0.0127 ($p>0.05$). Both precipitation and temperature trends are insignificant in the harvest stage. The correlation between precipitation and cotton yield is 0.3225 ($p>0.05$), and the correlation between temperature and cotton yield is 0.0433 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature trends are both insignificant, and they have an insignificant impact on cotton yield for this stage.

Table 4.9: Harvest stage precipitation and temperature trends and their correlation with cotton yield

County	Precip Trend (mm/year)	Corr between P&CY	Temp Trend (°C/year)	Corr between T&CY	Avg Max Temp Trend	Corr between ATmax & CY	Avg Min Temp Trend	Corr between Atmin & CY
Bailey	0.0007	0.3225	0.0127	0.0433	0.0054	-0.0152	-0.0200	-0.3180
Briscoe	0.0013	0.2192	0.0421*	0.3846*	0.0341	0.1083	-0.0134	0.0205
Castro	0.0007	0.1148	0.0441*	0.4054*	0.0283	0.1635	-0.0221	-0.0702
Cochran	0.0006	0.2559	0.0400*	0.3067	0.0357	-0.0132	0.0004	-0.2851
Crosby	0.0009	0.0886	0.0492*	0.3414	0.0551	0.0466	0.0005	-0.2187
Dawson	0.0009	0.2814	0.0124	0.0840	0.0445	0.0187	-0.0194	-0.1694
Deaf Smith	0.0008	0.0819	0.0402*	0.2629	0.0394	0.0670	-0.0365	-0.1356
Floyd	-0.0013	-0.0062	0.0208	0.1733	0.0111	-0.1739	-0.0004	-0.2869
Gaines	0.0025	0.1745	0.0570**	0.2683	0.0606*	0.0335	0.0572	0.0149
Hockley	0.0014	0.2395	0.0254	0.2679	0.0092	-0.0959	-0.0003	-0.2459
Lynn	0.0024	0.1000	0.0006**	0.4308**	0.0006*	0.1622	-0.0096	-0.2726
Parmer	0.0009	0.0505	0.0006**	0.2831	0.0006	0.0305	0.0003	-0.1076
Swisher	0.0033	0.0058	0.0326	0.4465**	-0.0076	-0.0767	-0.0005	-0.1149
Terry	0.0020	0.1557	0.0347	0.2068	0.0548*	0.0873	-0.0042	-0.2301

**p<0.01, very significant; *p<0.05, significant; p>0.05 insignificant.

In Briscoe County, the precipitation trend is 0.0013 ($p>0.05$), and the temperature is 0.0421 ($p<0.05$). There is an insignificant trend for precipitation but a significant trend for temperature in the harvest stage. The correlation between precipitation and cotton yield is 0.2192 ($p>0.05$), and the correlation between temperature and cotton yield is 0.3846 ($p<0.05$). There is an insignificant impact of precipitation on cotton yield but a significant impact of temperature on cotton yield. The average maximum temperature and average minimum temperature trends are both insignificant, and they have an insignificant impact on cotton yield for this stage.

The precipitation trend for Castro County is 0.0007 ($p>0.05$), and the temperature trend is

0.0441 ($p<0.05$). The temperature trend for this county is significant, but the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.1148 ($p>0.05$), and the correlation between temperature and cotton yield is 0.4054 ($p<0.05$). Precipitation has an insignificant impact on cotton yield at the harvest stage, while temperature has a significant impact on yield. The average maximum temperature and average minimum temperature trends are both insignificant, and also they have an insignificant impact on cotton yield.

Cochran County has a precipitation trend of 0.0006 ($p>0.05$) and temperature trend of 0.0400 ($p<0.05$). The precipitation trend is insignificant, but the temperature trend is significant. The correlation between precipitation and cotton yield is 0.2559 ($p>0.05$), and the correlation between temperature and cotton yield is 0.3067 ($p>0.05$). Both precipitation and temperature have insignificant impacts on cotton yield. The average maximum temperature and average minimum temperature have insignificant trends for this county at the harvest stage, and they also have an insignificant impact on cotton yield.

The precipitation trend for Crosby County is 0.0009 ($p>0.05$), and the temperature trend is 0.0492 ($p<0.05$). The precipitation trend is insignificant, but the temperature trend is significant. The correlation between precipitation and cotton yield is 0.0886 ($p>0.05$), and the correlation between temperature and cotton yield is 0.3414 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature both have insignificant trends for this county at the harvest stage, and they also have an insignificant impact on cotton yield.

Dawson County has a precipitation trend of 0.0009 ($p>0.05$) and a temperature trend of 0.0124 ($p>0.05$). The precipitation and temperature trends are insignificant. The correlation between precipitation and cotton yield is 0.2814 ($p>0.05$), and the correlation between temperature and cotton yield is 0.0840 (p>0.05). Both precipitation and temperature have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature trends are not significant, and they have an insignificant impact on cotton yield.

There is a precipitation trend of 0.0008 (p> 0.05) in Deaf Smith County, the temperature trend 0.0402 (p<0.05). The precipitation trend for this county in the harvest stage is insignificant, and but the temperature trend is significant. The correlation between precipitation and cotton yield is 0.0819 (p>0.05), and the correlation between temperature and cotton yield is 0.2629 (p>0.05). There is an insignificant impact of precipitation and temperature on cotton yield. The average maximum temperature and average minimum temperature have insignificant trends, and also they have an insignificant impact on cotton yield.

In Floyd County, there is a precipitation trend of -0.0013 (p>0.05), and the temperature trend is 0.0208 (p>0.05). Both precipitation and temperature trends are insignificant for this county in the harvest stage. The correlation between precipitation and cotton yield is -0.0062 (p>0.05) and the correlation between temperature and cotton yield is 0.1733 (p>0.05). Precipitation and temperature both have an insignificant impact on cotton yield. The average maximum temperature and average minimum temperature have an insignificant trend and also an insignificant impact on cotton yield.

The precipitation trend for Gaines County is 0.0025 (p>0.05), and the temperature trend is 0.0570 (p<0.01). Precipitation has an insignificant trend for this county, but the temperature has a very significant trend. The correlation between precipitation and cotton yield is 0.1745 (p>0.05), and the correlation between temperature and cotton yield is 0.2683 (p>0.05). Precipitation and temperature both have an insignificant impact on cotton yield. Also, in this county, the average maximum temperature has a significant trend of 0.0606 (p<0.05), but the average minimum temperature trend is insignificant. Both average maximum and minimum temperatures have an insignificant impact on cotton yield.

In Hockley County, the precipitation trend is 0.0014 ($p>0.05$), and the temperature trend is 0.0254 ($p>0.05$). The precipitation and temperature trends are insignificant for this county. The correlation between precipitation and cotton yield is 0.2395 ($p>0.05$), and the correlation between temperature and cotton yield is 0.2679 ($p>0.05$). There is an insignificant impact of precipitation and temperature on cotton yield. Both average maximum temperature and average minimum temperature have insignificant trends, and also they have an insignificant impact on cotton yield.

Lynn County has a precipitation trend of 0.0024 ($p>0.05$), and the temperature trend is 0.0006 ($p<0.01$). The precipitation trend for this county is insignificant, but the temperature trend is very significant. The correlation between precipitation and cotton yield is 0.1000 ($p>0.05$), and the correlation between temperature and cotton yield is 0.4308 ($p<0.01$). There is an insignificant impact of precipitation on cotton yield but a very significant impact of temperature on cotton yield. Both average maximum temperature and average minimum temperature have insignificant trends, and also they have an insignificant impact on cotton yield.

There is a precipitation trend of 0.0009 ($p>0.05$) in Parmer County and a temperature trend of 0.0006 ($p<0.01$). The temperature trend for this county is very significant, while the precipitation trend is insignificant. The correlation between precipitation and cotton yield is 0.0505 ($p>0.05$), and the correlation between temperature and cotton yield is 0.2831 ($p>0.05$). Precipitation and temperature have an insignificant impact on cotton yield. Both average maximum temperature and average minimum temperature have insignificant trends, and also, they have an insignificant impact on cotton yield.

In Swisher County, the precipitation trend is 0.0033 ($p>0.05$), and the temperature trend is

0.0326 ($p>0.05$). Both precipitation and temperature trends are insignificant for this county. The correlation between precipitation and cotton yield is 0.0058 ($p>0.05$), and the correlation between temperature and cotton yield is 0.4465 ($p<0.01$). There is an insignificant impact of precipitation on cotton yield but a very significant impact of temperature on cotton yield. Both average maximum temperature and average minimum temperature have insignificant trends, and also they have an insignificant impact on cotton yield.

Terry county has a precipitation trend of 0.0020 ($p>0.05$) and a temperature trend of 0.0347 ($p>0.05$). The precipitation and temperature trends are both insignificant. The correlation between precipitation and cotton yield is 0.1557 ($p>0.05$), and the correlation between temperature and cotton yield is 0.2068 ($p>0.05$). Both precipitation and temperature have an insignificant impact on cotton yield. Also, in this county, the average maximum temperature has a significant trend of 0.0548 ($p<0.05$), but the average minimum temperature trend is insignificant. Both average maximum and minimum temperatures have an insignificant impact on cotton yield.

4.4 Importance of Precipitation and Temperature to Cotton Yield to the Various Stages in the Growing Season

The following figures show precipitation or temperature needed at different stages of growth in all of the counties' understudy.

Figure 4.9 shows how important precipitation is in the different growing stages of cotton. The stars in different colors represent the correlation between precipitation and cotton yield for the various counties at different growing stages. The middle blue line represents the correlation between precipitation and cotton yield for all of the counties combined at the different growing stages of cotton.

In Figure 4.9, the seedling stage has a correlation of -0.0021; the leaf development stage has a correlation of 0.019, the flowering stage has a correlation of 0.1086, boll development stage has a correlation of 0.2107, boll opening stage has a correlation of 0.2458 and harvest stage has a correlation of 0.1048. From these correlations, precipitation is important for the boll opening stage. Because THP receives limited precipitation, farmers resort to the use of groundwater, the little precipitation that the area receives is important for the boll opening stage. The seedling stage is the only stage with a negative correlation between precipitation and cotton yield.

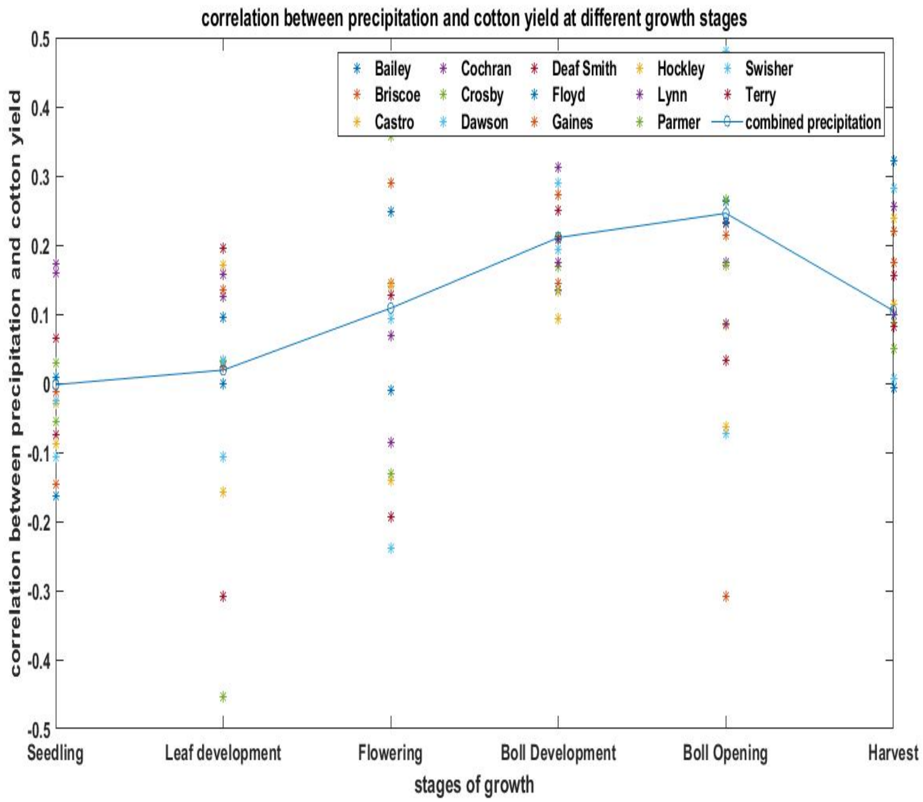

Figure 4.9: Correlation between precipitation and cotton yield at different growth stages

Figure 4.10 indicates how mean temperature is important at the different growth stages of cotton. The stars in different colors represent the correlation between mean temperature and cotton yield for the various counties at different growing stages. The middle blue line represents the correlation between mean temperature and cotton yield for all of the counties combined at the different growing stages of cotton.

According to Figure 4.10, the seedling stage has a correlation of -0.2544 between temperature and cotton yield, the leaf development stage has a correlation of -0.1935, the flowering stage has a correlation of -0.2262, the boll development stage has a correlation of 0.0264, the boll opening stage has a correlation of -0.3765, and the harvest stage has a correlation of -0.0832. All stages except the boll development stage has a negative correlation between temperature and cotton yield; therefore, an increase in temperature leads to a decrease in yield. The boll opening stage does not too much increase in temperature since an increase in temperature leads to a significant decrease in cotton yield.

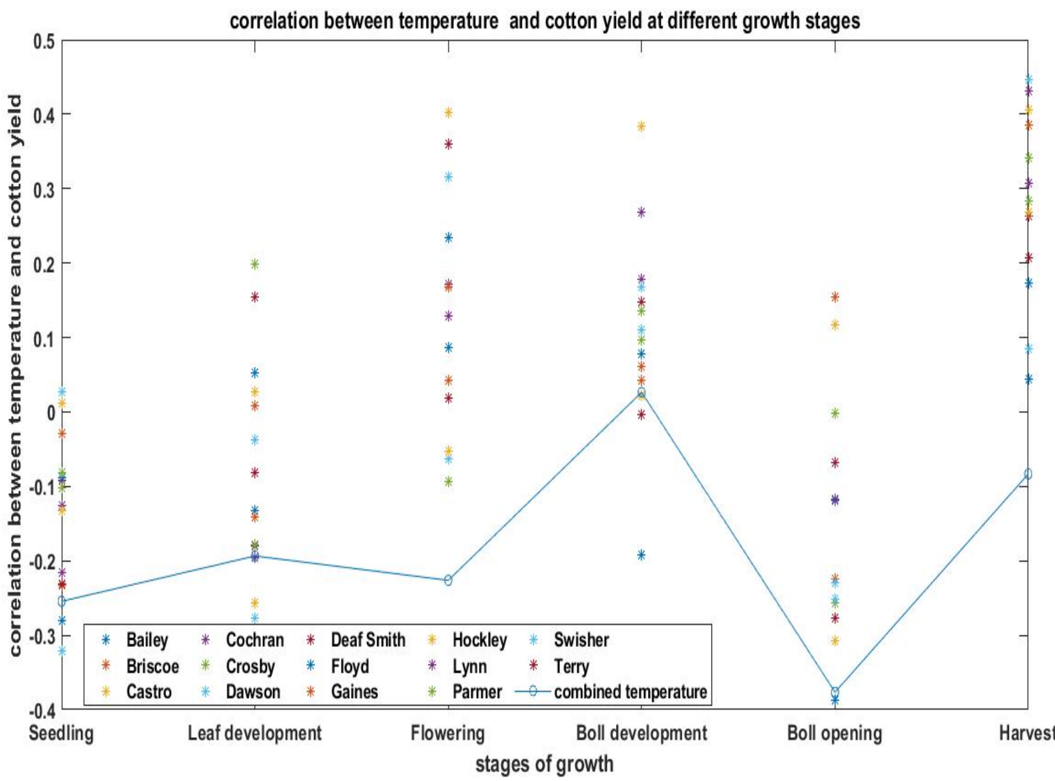

Figure 4.10: Correlation between mean temperature and cotton yield at different growth stages

Figure 4.11 shows the correlation between the average maximum temperature and cotton yield. The stars in different colors represent the correlation between average maximum temperature and cotton yield for the various counties at different growing stages. The middle blue line represents the correlation between average maximum temperature and cotton yield for all of the counties combined at the different growing stages of cotton.

In Figure 4.11, all stages have a negative correlation between average maximum temperature and cotton yield except for the boll development stage. An increase in temperature at the boll opening stage will lead to a significant decrease in yield; therefore, at this stage, not much temperature is needed.

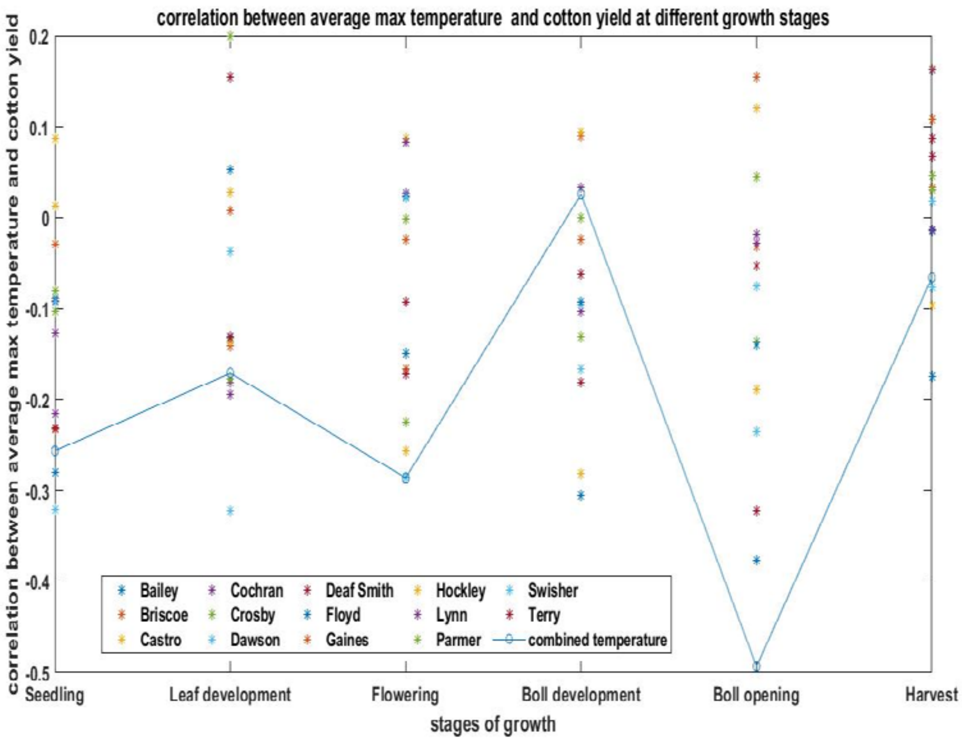

Figure 4.11: Correlation between average maximum temperature and cotton yield at different growth stages

Figure 4.12 shows the correlation between the average minimum temperature and cotton yield. The stars in different colors represent the correlation between average minimum temperature and cotton yield for the various counties at different growing stages. The middle blue line represents the correlation between average minimum temperature and cotton yield for all of the counties combined at the different growing stages of cotton.

According to Figure 4.12, all of the stages have a negative correlation between average minimum temperature and cotton yield except for the boll development stage. An increase in temperature at the boll opening stage will lead to a significant decrease in yield; therefore, at this stage, not much temperature is needed.

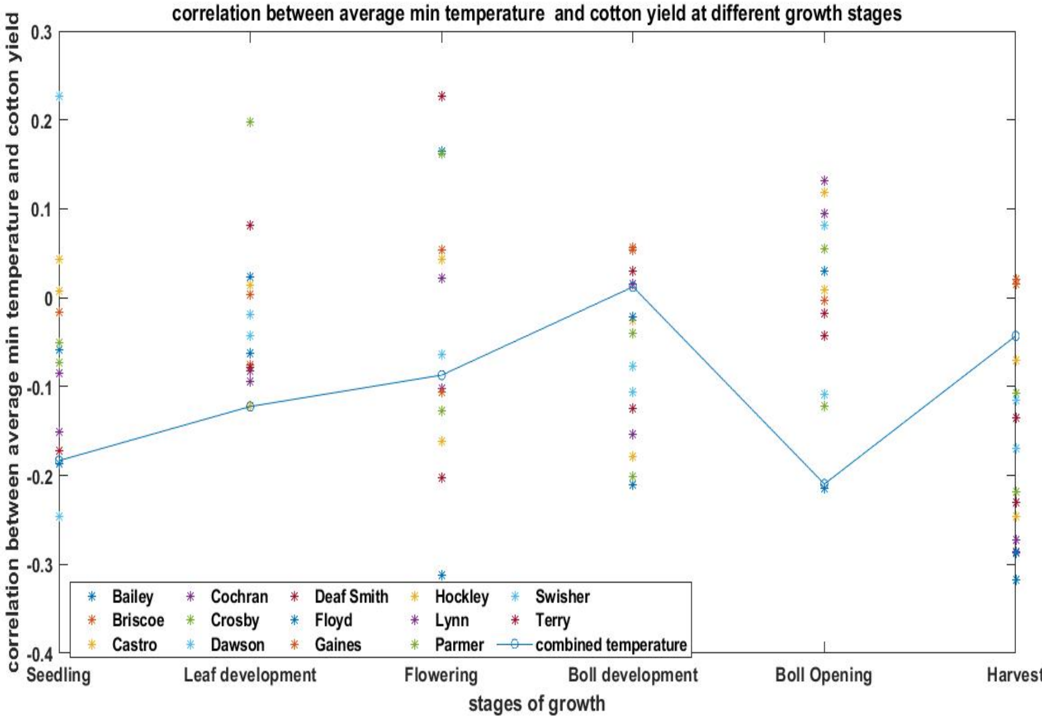

Figure 4.12: Correlation between average minimum temperature and cotton yield at different growth stages

4.5 Correlation between Groundwater Levels and Cotton Yield in Various Counties

Table 4.10 shows how groundwater is affected by cotton yield in the selected counties of the THP. The results on correlation between groundwater level and cotton yield were evaluated using correlation analysis. In Table 4.10, 12 counties show a very significant impact of groundwater on cotton yield, and two counties show a significant relationship of groundwater level on cotton yield. Precipitation received in the THP is very low, and the results indicate that groundwater is very important to farmers.

Table 4.10: Correlation between groundwater levels and cotton yield in various counties.

County	Correlation between groundwater level and cotton yield
Bailey	-0.4000**
Briscoe	-0.4403**
Castro	-0.3690**
Cochran	-0.4510**
Crosby	-0.5280**
Dawson	-0.3080*
Deaf smith	-0.3110**
Floyd	-0.5390**
Gaines	-0.4100*
Hockley	-0.3450**
Lynn	-0.5200**
Parmer	-0.5120**
Swisher	-0.4280**
Terry	-0.4170**

**p<0.01, very significant; *p<0.05, significant; p>0.05 insignificant.

4.6 Spatial Analysis of the Correlation between Groundwater Level and Cotton Yield

In Figure 4.13, the dark blue color represents counties with a higher negative correlation between cotton yield and groundwater level, and light blue colors represent counties with a lower negative correlation between cotton yield and groundwater level. Floyd and Crosby counties have the highest correlation between cotton yield and groundwater level, Parmer and Lynn counties have a higher correlation between cotton yield and groundwater level. Swisher, Briscoe, Cochran, and Terry counties have a low correlation between cotton yield and groundwater level; Bailey, Gaines, and Castro counties have a lower correlation between cotton yield and groundwater level. Lastly, Deaf Smith, Hockley, and Dawson counties have the lowest correlation between cotton yield and groundwater level.

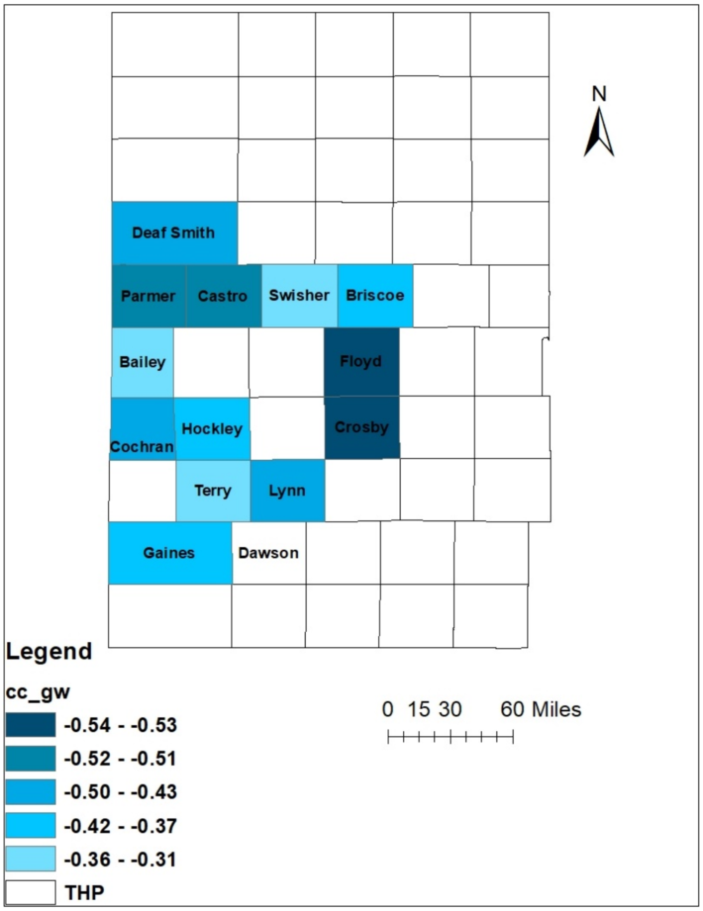

Figure 4.13: Map showing the correlation between cotton yield and groundwater level

CHAPTER 5

SUMMARY AND CONCLUSION

This chapter reflects on the major findings of the spatiotemporal analysis and interrelationship between cotton yield and climate change in the THP.

Cotton is a type of a cultivated plant that has found a variety of industrial uses. It is among the world's most cultivated crops. The literature reviewed so far seek to suggest a damaging effect of climate change on cotton production, especially in arid and semiarid regions. However, other works of literature also suggest that cotton plants can withstand climate variability. As a result, this study sought to look at the spatiotemporal analysis and interrelationship between cotton yield and climate change in the THP region. Specifically, the study sought to:

1. Assess the climate change in the Texas high plains
2. Examine the impacts of climate change on cotton yield
3. Assess the impacts of groundwater decline on cotton yield.

The study made use of data from the United States Department of Agriculture (USDA), National Climatic Data Center (NCDC), and the United States Geological Survey (USGS). The data was analyzed using trend analysis and correlation analysis.

5.1 Main Findings

The research shows that out of 14 counties that were studied, nine counties showed a very significant trend in annual mean temperature and five showed an insignificant trend. Annual precipitation trend for all 14 counties were insignificant. From these results, we can conclude that, on average, the inter-annual variation in annual precipitation in the area is insignificant, but the annual mean air temperature has increased. These findings confirm the climate change projections for the Texas High Plains and Rolling plains (Modala et al., 2017; Karl et al., 2009).

Annual precipitation showed an insignificant correlation with cotton yield for all 14 counties. Annual mean temperature showed a very significant correlation on cotton yield for one county, a significant correlation for four counties and an insignificant correlation for nine counties. This result concurs with the findings of Ray et al. (2018) that drought (climate change) has lesser impacts on cotton in the THP.

In the growing season of cotton, precipitation showed an insignificant trend, and also an insignificant correlation with cotton yield for all 14 counties. Growing season mean temperature showed a very significant trend for five counties and a significant trend for two counties, and an insignificant trend for seven counties. The impact of growing season mean temperature on cotton yield is very significant for one county, which is Castro County and insignificant for other 13 counties.

The correlations between cotton yield and climate variables (temperature and precipitation), as well as their trends, were analyzed in different cotton growing stages. Results showed that at the seedling stage, precipitation trends are insignificant, and also, have an insignificant impact on cotton yield for all 14 counties. Air temperature has insignificant trends for all counties at this stage and an insignificant impact on cotton yield.

At the leaf development stage, precipitation trends are insignificant for all 14 counties. There is an insignificant impact of precipitation on cotton yield for 13 counties, but a significant impact of precipitation on cotton yield for Parmer County. Air temperature has insignificant trends for all counties at this stage and an insignificant impact on cotton yield.

At the flowering stage, precipitation has insignificant trends for all 14 counties. There is an insignificant impact of precipitation on cotton yield for 13 counties but a significant impact on cotton yield for Crosby County. The air temperature trend is very significant for five counties, significant for two counties, and insignificant for seven counties. The impact of temperature on cotton yield is significant for two counties and insignificant for 12 counties.

At the boll development stage, precipitation showed an insignificant trend, and also an insignificant impact on cotton yield for all 14 counties. The air temperature trend is insignificant for six counties, significant for one county and very significant for seven counties. The impact of temperature on cotton yield is significant for one county and insignificant for 13 counties.

At the boll opening stage, precipitation trend is insignificant for all 14 counties. There is an insignificant impact of precipitation on cotton yield for 13 counties, but a significant impact of precipitation on cotton yield for Swisher County. Air temperature has insignificant trends for all counties. There is an insignificant impact of temperature on cotton yield for 13 counties but a significant impact of air temperature on cotton yield for Bailey County.

At the harvest stage, precipitation trend is insignificant for all 14 counties, and also, there is an insignificant impact of precipitation on cotton yield. The air temperature trend is insignificant for six counties, significant for five counties and very significant for three counties. The impact of temperature on cotton yield is very significant for two counties, significant for two counties and insignificant for ten counties.

Again the research found that precipitation is important in the boll development and boll opening stages looking at all of the counties as a whole; this asserts the results of Ritchie et al. (2007), which found out that extreme temperatures and low water availability can reduce fiber length. The boll opening stage needs lower levels of air temperature, this asserts the findings of Reddy et al. (1999), which found out that boll size and maturation periods decreased as temperature increased and also boll growth declined at the highest temperatures.

The research also found that groundwater is very important to farmers in the THP, considering the amounts of precipitation received in the area. From the results, 12 counties have a very significant relationship with cotton yield, and two counties show a significant relationship. this concurs the results of Closas and Molle (2018) which concluded that extracted water became a source of irrigation to crops including cotton in the THP.

5.2 Conclusions

Cotton is essential for the survival of humankind. Due to its contribution to the development of civilizations over the past centuries. Throughout history, many counties have tried to rely on cotton as a source of income, job creation, and tax revenues, and therefore, this study provides an insight into the spatiotemporal analysis between cotton yield and climate change since climate could cause negative impact on crop yield. From the study, there is an increase in temperature on average in the THP. Precipitation, on the other hand, shows an insignificant trend. Annual precipitation has an insignificant correlation to cotton yield. Temperature has lesser impacts on cotton yield since annual mean temperature shows a very significant impact on cotton yield for one county, a significant impact for four counties, and an insignificant impact on nine counties. In the growing season of cotton yield, precipitation has an insignificant trend for all counties, and there is an insignificant correlation of precipitation on cotton yield. The mean air temperature in the growing season has a very significant trend for five counties, a significant trend for two counties and an insignificant trend for seven counties. The correlation between mean air temperature and cotton yield in the growing season is insignificant. Also, precipitation is important at the boll development and boll opening stages to increase fiber length. Precipitation can be supplemented with irrigation if it is not enough. The boll opening stage needs lower levels of air temperature, and this is because higher levels of temperature reduces boll size, boll maturation as well as boll growth. Lastly, groundwater is very important to farmers in the THP, considering the amounts of precipitation received in the area. The cotton yield in the THP has an increasing trend due to increase irrigation in the area, this may contribute to the decline in groundwater resources in the area.

5.3 Limitations and Recommendations

The research could have used GIS and remote sensing to correlate climate variables and cotton yield spatially. Also, it could have used remote sensing data on cotton to estimate yield for various counties in the THP, but all of these were not accomplished due to lack of time. Therefore, this research recommends future studies to spatially analyze the correlation between climate variables and cotton yield and also spatially estimate cotton yield based on spatial data.

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