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North Dakota Spring Wheat Yield In Relation To Temperature And Precipitation

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NORTH DAKOTA SPRING WHEAT YIELD IN RELATION TO TEMPERATURE AND PRECIPITATION

by

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This thesis, submitted by Manna Begum Khan in partial fulfillment of the requirements for the degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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ABSTRACT

Global ocean and land temperature is rising. The Intergovernmental Panel on Climate Change (IPCC) 2014 report indicated the global average combination of land and ocean surface temperature increase 33.53° F (0.85°C) over the last 1400 years in the Northern Hemisphere (IPCC 2014). Global temperature and precipitation patterns are changing; it affects North Dakota wheat production. This crop remains crucial to the state's economy even with the rise of corn and soybean production. Temperature and precipitation change's effect in North Dakota already has been observed with shorter and milder winters. The study area is the state's nine agricultural districts determined by the United States Department of Agriculture (USDA). The climate data was collected from the National Oceanic and Atmospheric Administration (NOAA), and agriculture data for spring wheat was obtained from the National Agricultural Statistics Services (NASS). The research investigated if temperature and precipitation variability influence spring wheat yield in the period of 1986-1990 compared to period of 1991-1995. It was hypothesized that an increase in temperature will decrease spring wheat yield and that an increase in precipitation will increase spring wheat yield. The results show that warmer temperatures and drought conditions are detrimental to spring wheat production in comparison to precipitation. Increases of precipitation would not necessarily provide increases in spring wheat yield. The overall North Dakota's spring wheat yield is governed by inter-annual variability in temperature and precipitation. Thus, this study has importance in better understanding North Dakota's future spring wheat production in a time of global climate change.

CHAPTER 1

INTRODUCTION

1.1 Background

Globally, there are demands for food which will continue to rise. There are many reasons for this rising food demand including population increase, loss of agriculture lands, increased urbanization, changing lifestyles seen in eating habits, and higher income. In addition, other reasons for rising food demands are food price increases, climate change, and less investments in the agricultural sector. The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) 2012 report indicated that world food demand may increase by 70 percent by 2050 with the key drivers of food demand being population growth, continuing income growth per person, and the fast growing urbanization in the developing countries, particularly in Asia, Eastern Europe, and Latin America (Linehan, et al. 2012). Worldwide, many people consume a large portion of carbohydrates for their daily diet. For example, the foods of choice in Vietnam, Pakistan, and Mexico, respectively are rice, grains, and corn. Furthermore, wheat is one of the major crops that helps to meet the world's demand for carbohydrates. One of the crops the United States specifically relies on for carbohydrates is wheat. "Wheat is the third largest crop in the world behind corn and rice, and an essential source of carbohydrates for millions of people" (Asseng, et al. 2011). The south and the east part of North Dakota's is known as part of the United States' "breadbasket" among the other states. North Dakota is known, as being a major producer of wheat in the United States, and wheat plays a major role in North Dakota's economy. As a benchmark from 2001 through 2003, the wheat industry in North Dakota total gross annual income was $3.6 billion (Bangsund and Leistritz 2005). To survive, much human-consumed food is either directly or indirectly a product of soil; agriculture is one of the most important activities on the earth (Fred 1961). Socio-economic, political, climate, and other factors may control North Dakota wheat yield. When dealing with wheat yield, there are compounding factors related to wheat production including soil types, temperature, precipitation, fertilizer, irrigation, and plant disease. North Dakota history tells us that fertile soils, abundant land, (Curtis 2002). According to the Koppen climate classification system, four major climate groups cover the United States: dry, mild mid-latitude, severe mid-latitude, and highland. More specifically, North Dakota is located in the severe mid-latitude and dry climate group where summers are hot, evaporation exceeds precipitation, and very cold severe winters are experienced (Hess 2011).

Although North Dakota climate has been a vital support for wheat growth, if North Dakota's climate shifts, then the wheat production will decline. Due to current climate change, the main characteristics of weather temperature and precipitation patterns has been changing. The effects of temperature and precipitation change in North Dakota has already been observed through shorter and milder winters. Global temperature and precipitation patterns are changing, and this is a regional issue in North Dakota which affects wheat production. A study done by Bora, et al. (2014) already has shown that the spring wheat yield mainly depends on the climatic changes during growing periods from April to September. That research indicated that a similar effect could occur in North Dakota's wheat production.

North Dakota wheat production is also threatened by climate change, thus the wheat yield will decline. Wheat is one of the most important crops because agriculture is a major industry in North Dakota.

1.2 Purpose

The primary goal of this study is to evaluate the possible impacts of temperature and precipitation in North Dakota as it affects North Dakota's spring wheat yield. This study is important because wheat not only influences the United States economy but also impacts the global economy and markets. Farmers would benefit from this study because they are the ones most effected by crop yield decrease. In addition, this research can give feedback and prove helpful in future studies. This research asks the following questions:

1) Do temperature and rainfall variability influence North Dakota Red Hard Spring Wheat (spring wheat) production during the growing season?

2) What are the impacts on yield for spring wheat in North Dakota in the period of 1986-1990 vs. the period of 1991-1995?

This study focused on the relationship between temperature and precipitation, and it specifically emphasized analyzing spring wheat yield by synthesizing data from the state of North Dakota for the periods of 1986-1990 and 1991-1996. This study is important in North Dakota because spring wheat yield has not been the subject of this type of quantified research as related to case studies of temperature and precipitation. As a result, this search will identify where temperature and precipitation have had any impact on spring wheat yield, given the specific location and periods included in the study.

Climate change is a complex and controversial issue. The impact of climate change could be observed in the long term, but people do not realize the negative consequences in a short time period. This study is important because there is a shifting relationship to food production. Climate change plays a huge role in spring wheat production. With this study, the data analyzed supports the generalization of climate change's existence and its influence on North Dakota's spring wheat yield.

1.3 Hypothesis

The hypothesis of this study anticipates finding the first period with less wheat crop yield because 1988 was a dry year. It is expected to see high wheat crop yield during the second period because 1993 was a wet year. The overall, spring wheat yield depends on inter-annual variability in temperature and precipitation in North Dakota.

The state of North Dakota's 53 counties are divided into nine agricultural districts per the United States Department of Agriculture (USDA). For this study, the methodology includes using Excel data entry for temperature and precipitation, creating maps in ArcGIS, and producing tables and graphs to present the statistical analysis regarding these agricultural sub-regions. This statistical analysis used a combination of descriptive statistics, difference of means tests, and coefficient of variation results based on the study objectives.

The Intergovernmental Panel on Climate Change (IPCC 2014) report indicates that in the next century the frequency of extreme climate events such as temperature and precipitation will be increase globally due to climate change. The report also specifies that global mean temperature has been increased 1°C to 3°C since preindustrial time, and it will continue to increase. As a result, some locations will be benefited from excess water for a short time, which would allow crops to increase; however, other areas will experience very hot and dry situations (IPCC 2014). Therefore, increases in temperature and precipitation will also directly impact North Dakota's spring wheat yield. The impact will not only influence North Dakota's economy but also shrink global food security.

CHAPTER 2

LITERATURE REVIEW

The theoretical framework and empirical research of my study considers sub-disciplines of Geography. These sub-disciplines include physical, agricultural, economic, and historical geography.

2.1 Historical Geography

Between the years 1774 to 1924, the United States was divided into several agricultural regions based upon a combination of factors such as soil, topography, rainfall, temperature, sunshine, accessibility to market, character and genius of the people, education, effectiveness of scientific research, and transportation facilities. These regions were altered as cropping zones by the changes in agricultural policies (Coulter 1925). In particular, diversities of farming systems created many varying characteristics in the Great Plains Region. In the early 1900s, the spring wheat belt experienced a surplus of wheat production in response to new forms of marketing. In the early 1900s, spring wheat was established in the Great Plains region and the state of North Dakota was largely in the spring wheat area (Coulter 1925). However, the influence of World War I (WWI) policies, plant diseases, and the Great Depression caused changes in government policy which decreased wheat production (Coulter 1925; USDA 1985; and North Dakota Studies 2018). The Great Depression of the 1930s was complex, challenging, and tough to resolve. It affected tremendously North Dakota's economic activities. In addition, the 1930s was a time of extended and intense drought that made the economic problem more complicated to North

Dakotans. As a result of the Great Depression and drought, there was limited crop production, loss of livestock and farmers sold more agricultural products at lower prices (North Dakota Studies 2018). From 1919 to 1924, the farmers decreased their acreage by 18.3 percent in response to lower wheat prices. Between the years 1933 to 1983, the number of farms decreased, and average farm size (acres) increased due to agricultural pushes and farming technology developments (Coulter 1925 and USDA 1985). In the 1920s and 1930s, the combination of low prices, poor crops yield, and drought forced many farmers off the land (North Dakota Studies 2018). It was necessary to reorganize and readjust agricultural programs in the spring wheat area and the Great Plains region for agricultural recovery. Also a concern existed for diseases such as rust, smut, scab, and root rot that resulted in lower yields, quality, and price breaks in 1920-21 (Coulter 1925).

2.2 Physical Geography

The geological record reveals that in the past, Earth's climate was markedly different from today; however, the phenomenon of climate change is partially a result of human activities (Hess 2011). According to the Koppen climate classification system, the United States is situated on four major climate groups: dry, mild mid latitude, severe mid latitude, and highland. North Dakota is located in the severe mid latitude and dry climate group where summers are hot, evaporation exceeds precipitation, and very cold, severe winters are experienced (Hess 2011).

Many researchers have predicted the effect of future climate change on crop production using a combination of field studies, statistics, and models (Lobell 2003; Asseng, et al. 2011). The Asseng, et al. (2011) study focused on a global scale using a sound simulation model and also a novel approach to estimate the effect of temperature variability on wheat yields by separating natural temperature effects from all other weather and technical effects. This modelling can also consider the timing of each climatic factor at each stage, and this is critical for any impact analysis (Asseng, et al. 2011). Furthermore, Asseng, et al. (2011) points out that the frequency of heat events above 93.2ºF (34ºC) on average maximum temperatures during grain filling, the large negative impact of small increases in average temperature on wheat production, is applicable not only in Australia, but also to the major wheat cropping regions in the world. A similar study has been done by Bora, et al. (2014), *Impact of Climate Variability on Yield of Spring Wheat in North Dakota, which* focuses on average air temperature, precipitation, and soil temperature from 2007 to 2011 for three counties (Cavalier, Grand Forks, and McHenry). The results show that the average minimum and maximum air temperatures affect yield with average maximum air temperature significantly different from April to September. In addition, average low soil temperatures, excess rainfall, and solar radiation caused low spring wheat yield (Bora, et al. 2014). However, my study emphasizes the relationship between temperature, precipitation, and spring wheat yield comparing two time periods from 1986-1990 and 1991-1995 by creating climographs, graphs, and statistical analysis for nine counties in North Dakota which has not been measured previously in this fashion. Thus, by using temperature and precipitation data, the researcher is able to separate the impact of temperature and precipitation from other factors and show the effect of these on spring wheat production.

2.2.1 Temperature

Global average temperatures have increased over the last few decades and are predicted to continue to rise (Asseng, et al. 2011; Strain 2011; IPCC 2014; and NOAA 2018). Averaged as a whole, the temperature across global land and ocean surfaces for April 2018 was 33.4°F (0.83°C) above the 20th century average of 56.7°F (13.7°C), and the third highest April temperatures were observed since records began in 1880 (NOAA 2018). Temperature has increased approximately to 35.6 °F or 2 °C (above the preindustrial baseline) due to climate change; this is very likely to lead to more frequent extreme heat events and daily precipitation extremes over most areas of North America which may result in more frequent low-snow years and shifts toward earlier snowmelt runoff over much of the western USA and Canada (Romero-Lankao, et al. 2014). North Dakota, specifically, has experienced one of the largest temperature increases of any neighboring American state, with annual average temperatures increasing at a rate of 0.26 ºF per decade (Frankson and Kunkel 2018). Since 1980, this increase is most evident in winter warming, which has been characterized by the below average occurrence of extremely cold days (Frankson and Kunkel 2018).

North Dakota is a semi-arid state where a person likely finds it to have unpredictable extreme weather conditions with some years experiencing either very dry or wet periods; consequently, some years the state faces either drought or flood events. Therefore, both extreme dry and wet weather conditions are detrimental to spring wheat yield. Average January temperatures in North Dakota ranges from 0 ºF in the northeast to 15 ºF in the southwest, while average July temperatures range from 65 ºF in the northeast to 72 ºF the southwest (Frankson and Kunkel 2018). Temperatures of 100 ºF or more are most prevalent in the drier southwestern and south-central regions (Frankson and Kunkel 2018). During the 1930s, long-term drought caused the topsoil to be exposed to wind and water erosion in many states including North Dakota. Partially as a result of having lost topsoil, the seeds-sprouted plants did not grow properly (North Dakota Studies 2018).

The 1930s were not the only drought years in North Dakota. Because of the State's semi-arid climate condition, drought can be expected at any time, and it has been a constant problem for farmers (North Dakota Studies 2018). Besides the 1930s Dust Bowl, both in 1955 and 1988, North Dakota had experienced heat wave and drought conditions, which were less known drought episodes. Thus, farmers practice no-till agricultural methods to prevent surface soil erosion because droughts and floods are recurring climatological problems in North Dakota (North Dakota Studies 2018). Both drought and flood are detrimental for crop production. For example, long term drought and poor agricultural practices that created the Dust Bowl began in 1930 and occurred intermittently until 1939. It severely affected 27 states (75% of the country). Approximately 2.5 million farmers and their families left the Plains region and migrated to California's Central Valley to labor as farm workers (Richardson 2015). Higher temperatures will increase the duration of the warm season causing soil-moisture depletion, leading to more serious drought conditions (Frankson and Kunkel 2018 and North Dakota Studies 2018).

Various crop-growing models have been employed by researchers to simulate the impact of increasing temperature during the growing season on crop production (Lobell and Asner 2003; Asseng, et al. 2011; and Yang, et al. 2017). The crop growing models widely used to quantify different crop yields include General Circulation Models (GCMs), Cropping System Models (CSM), and Decision Support System for Agro-technology Transfer (DSSAT) (Jones, et al. 2003; Yang, et al. 2017). The increasing magnitude of adverse and extreme weather events will challenge the future wheat production as seen in Yang, et al. (2017). This previous study showed the impact of increasing heat stress events on wheat yield using a wide range of General Circulation Models (GCMs) with observational data used to produce more detailed projections of local climate. The crop growth model CSM-CropSim wheat of DSSAT 4.5 is used in China to quantify yield damages caused by heat stress (Yang et al. 2017). Early work by Lobell and Asner (2003) used a statistical model that concluded that gradual temperature change has had a measurable impact on crop yield trends including spring wheat.

2.2.2 Precipitation

North Dakota is known for a large range of temperature variations that have unpredictable patterns on an inter-annual basis. Likewise statewide average annual precipitation varies from year to year. It ranges from less than 14 inches in the northwest to 22 inches in the southeast (Climate of North Dakota 2018; Frankson and Kunkel 2018). In the northwest, the lowest precipitation recorded (8.81 inches) was in 1936, and the highest precipitation was recorded (23.48 inches) in 2010 (Frankson and Kunkel 2018). The wettest multi-year periods were in the 1940s and 1990s; most of the precipitation falls during summer months (Frankson and Kunkel 2018). Furthermore, North Dakota experiences drought and wet conditions on a varying basis; 1988 was an extreme heat wave and 1993 was a wet year. In general, temperature and precipitation play a huge role in wheat yield. Too much water can cause flooding during the planting season and too little precipitation can cause drought. Historically, North Dakota is a flood-prone area, and there are many factors that cause heavy floods. Among the factors heavy winter snowfalls and rainfalls can cause floods. During the winter 1996-1997, nine major blizzards and four winter storm's resulted in melting snowfall causing floods all along the Red River Valley. This event damaged thousands of acres of productive farmland. Heavy precipitation events are projected to increase during the colder times of the year (Frankson and Kunkel 2018). This will most likely cause flooding and damages to spring wheat production. Since an increase of temperature can cause snow to melt quickly in the spring, any additional rainfall may lead to flooding.

2.3 Agricultural Geography

Wheat was one of the first domesticated crops and was cultivated for 8000 years in the major civilizations of Europe, West Asia, and North Africa. Today, it can be grown within the

Arctic Circle and at higher elevations near the equator (Curtis 2002). However, wheat can grow most successfully between the latitudes of 30^{o} and 60 ^{o}N and 27^{o} and 40 ^{o}S (Nuttonson 1955).

Following China and India, the United States is the third largest wheat-producing country in the world (Yang, et al. 2017). Wheat has been the king and dominant crop since the prairie was first plowed in the late 1800s (Ydstie 2014). Due to climate change, these historical crops and current activities agriculture will be hurt (Ydstie 2014). During the early 1900s, North Dakota produced 103,153,000 bushels of spring wheat and the greatest single block of premium wheat in the country after Kansas (Bridston and Hamilton 1922). North Dakota has been a leader in wheat production, both in hard red spring wheat, usually used for baking breads and durum wheat usually used to make pasta (North Dakota Agriculture 2017-2018).

2.3.1 Spring Wheat

Wheat is grown in a variety of environments, and it is produced all over North Dakota. Climate plays a huge role in crop yield although climatic conditions are not uniform throughout North Dakota. When climatic and soil conditions are favorable for a crop, a high quality and quantity crop would be expected (Bora, et al. 2014). Historically, North Dakota has been a top producer of durum and spring wheat; other top spring wheat producing states include Kansas, Montana, Minnesota, and South Dakota. Hard red spring (HRS) wheat accounts for about 20 percent of production and is grown primarily in the Northern Plains: North Dakota, Montana, Minnesota, and South Dakota (USDA 2018). Production is concentrated in North Dakota, the Red River Valley, and the yields are generally highest in the northern third of the state (Bangsund and Leistritz 2005). The average growing season in North Dakota is 110 days in the northeast regions, 120 days in north-central regions, and 130 days in the south-east and south-central regions (Climate of North Dakota 2018). During grain filling, worldwide seasonal temperature conditions are similar to those of the major wheat-growing regions, and about 75 percent of the annual precipitation falls during the crop-growing season (Asseng, et al. 2011; Climate of North Dakota 2018). North Dakota has a short growing season compared to other states; however, fertile soil and long hours of sunshine make it possible to grow many crops in the state including wheat (Climate of North Dakota 2018). In 2002, North Dakota led the nation's 2nd place spring wheat producing state (Agriculture-North Dakota 2018).

Temperature and precipitation are not the only reasons spring wheat yield fluctuates. There are many factors that influence spring wheat yield. One of the factors is the farmers' decision of what crops they will plant for profit. There has been a big shift from wheat to corn for ethanol in recent years due to warmth and moisture conditions, which have helped corn and soybeans succeed in North Dakota (Ydstie 2014). Thus, the spring wheat yield decreased because the farmers are planting more corn, soybeans, and other crops for profit. Another factor that influences wheat yield in North Dakota is scab and rust diseases. Stem rust, a fatal fungal infection of Hard Red Spring (HRS) wheat first appeared in the early 1900s which caused serious damage to HRS wheat production in 1904 (North Dakota Studies 2018). North Dakota farmer Dan Selvig noted that wetter conditions helped convince his family to shift their plantings to corn because wheat hates humidity, a condition which promotes scab and rust diseases (Ydstie 2014). Larry Slabaugh, a 70-year-old farmer, stated without a doubt that more wet seasons have come along since 1993 and the pattern has really changed (Ydstie 2014). Daryl Ritchison, then North Dakota's assistant state climatologist, indicated that the average rainfall has been two to three inches greater in the past two decades in North Dakota. He added that the increase of rainfall is a big change from the semi-arid conditions that prevailed in the past 60 years; because of a warming trend, the growing season also increased two to three days a year in the last couple decades, and by two weeks over the past century (Ydstie 2014).

Over the years, the total number of farms has decreased while the average size of farming operations has increased (Bangsund and Leistritz 2005; Agriculture-North Dakota 2018) which could cause reduced wheat production. This is due to many family farms shifting to operating more as corporate farms. Other factors include soil type and productivity, specialty crops such as peas, lentils and potatoes, management and production practices (Coulter 1925; Holdman 2015; and Swenson 2017).

2.3.2 Spring Wheat Growth Development and Yield

HRS wheat is a specialty wheat grown primarily in the Northern Plains, and North Dakota's spring wheat is known for its high quality (North Dakota Wheat Commission 2015). North Dakota spring wheat average yield ranged from 3.3 bushels per acre in 1936 to 30.8 bushels per acre in 1971, and the state average spring wheat yield for the 65-year period (1936-1971) was 16.2 bushels per acre. The state average yield has increased at an average annual rate of 0.3 bushels per acre. The yield improvement reflects changes in cultural practices, fertilizer management, and inherent productivity of the varieties grown (Cambell 1987). Wheat growth is determined by temperature, cultivar, availability of water and nutrients, and light intensity. Thermal time, as measured by growing degree days, more accurately predicts development than calendar days (Bauer, et al. 1992).

The growth cycle of wheat has the following stages: germination, seedling establishment and leaf production, tillering and head differentiation, stem and head growth, head emergence and flowering, and grain filling and maturity. The germination process begins, when a kernel is sown into moisture; the water use is minimal but drought stress during this early stage of development can reduce the number of tillers and root mass. Tillering is an important development stage when plants create good growing conditions. During tillering time the main crown root system, the floral structures and kernels already are being formed. The main crown root system provides the plant most nutrients and water during the growing season (Fowler 2019). Drought and heat stress during this period should be minimized; cool weather during this early phase of development favors more uniform tillering and large spikes. Head emergence and flowering stage is extremely sensitive to high temperatures and freeze can cause floret abortion and reduction in grain weight (Wiersma and Ransom 2005).

Spring wheat is considered a small grain, according to Wiersma and Ransom (2005) and for high yields a small grain needs 14 to 17 inches of water depending on weather conditions and length of growing season. The water used for optimum growth is a combination of stored soil moisture, rain, and irrigation. Small grains require about six inches of water as a threshold for grain yield, and each additional inch of water will provide four to five bushels per acre. In deep, well-drained soils, the roots of small grains will extract water to a depth of 3 to 3.5 feet (Wiersma and Ransom 2005).

2.4 Economic Geography

Agriculture is North Dakota's largest industry; approximately 90 percent of the state's land is used for crop farming and cattle ranching with about 24 million acres of cropland. On average, North Dakota farmers plant about 7.5 million acres of wheat with a total production is 320 million bushels. North Dakota and Kansas are most often the top two wheat-producing states (North Dakota Wheat Commission 2019). North Dakota is the ninth largest agricultural exporting state and the top state for wheat exports in the United States, according to the most recent Census of Agriculture. Since 1989, North Dakota has accounted for 14 percent of all wheat produced in the United States, and historically led for spring and durum wheat into the 21st Century (Bangsund and Leistritz 2005). All wheat industry activities, from direct and secondary economic impacts, generated gross business of about $3.6 billion annually from 2001 through 2003 (Bangsund and Leistritz 2005). The direct and indirect impacts from the wheat industry on the economy of North Dakota include: wheat production, transportation, grain handling, and processing (Bangsund and Leistritz 2005). The wheat industry directly affects on-job, in-grain handling, and transportation, but the actual number of those jobs was not estimated. The industry indirectly supported about 35,041 full-time jobs annually in North Dakota (Bangsund and Leistritz 2005). By 2015, the value of wheat exports reached $988.4 million, and the state's crop brought in $1.6 billion in annual cash receipts (North Dakota Agriculture 2017-2018). North Dakota is akin to being the world's superstore, exporting agricultural commodities and products to different countries. Adding value to farm products before they leave the state creates more jobs and delivers a broad range of positive economic impact (North Dakota Agriculture 2017-2018). North Dakota is known as an agriculturally-based rural economic state. North Dakota's farmers are feeding people across the United States and the world. North Dakota's economy heavily relies on agriculture, and exports are extremely important to the state's agricultural industry and economy (Bangsund and Leistritz 2005; North Dakota Agriculture 2017-2018). Wheat perhaps is the single most important enterprise for farmers, and the state has a long reputation as being a major wheat producer in the United States (Bangsund and Leistritz 2005).

From 1980 to 2008, worldwide farms produced 5.5 percent less wheat due to rising temperature. Less wheat yield could have contributed to increases in food prices of 18.9 percent since 1980. Farmers could have produced a lot more food if the weather had been cooler (Strain 2011). This is because rising temperatures can cause reduced soil moisture.

2.5 Consequences of Extreme Climate Events

The consequences of extreme climatic events are important to recognize in North Dakota. For example, "During the spring and summer of 1988 the northern Great Plains suffered one of the warmest, driest periods in its recorded history" (T. Luke George, et. al 1992). In another example, excessive precipitation produced severe flooding in the Upper Midwest during the summer of 1993 (Strobel, et al. 1997; Larson 1997), including North Dakota spring wheat. "A wet weather pattern that persisted over the Upper Midwest for several months in mid-1993 culminated in intense, persistent precipitation in late June and July" (Strobel, et al. 1997); monthly rainfall in the upper Mississippi River Basin was greater than climatic normal (period from1961-1990) for January through June 1993 (Wahl, et. al 1993). In North Dakota, the most severe flooding occurred in the Devils Lake basin, the Red River of the North region, and upper James River basin. A total of 39 counties in North Dakota were declared disaster areas (Strobel, et al. 1997). The city of Fargo received about 185 percent of the normal rainfall for July (NOAA 1993). Climate change has triggered patterns of temperature and precipitation change across the globe, affecting some locations. The global population has been increasing at an exponential rate since the industrial period. The world population reached 7 billion in 2012, and the current world population is 7.7 billion. It is projected to reach more than 9 billion by 2050 (FAO 2019; U.S. Census Bureau 2019). Having now covered the literature review for this topic, the next chapter is focused upon the methodology for this research.

CHAPTER 3

METHODOLOGY

North Dakota is situated in the north-central continental interior of the United States, and it is characterized by hot summers, very cold winters, and sparse to moderate rainfall, with periods of drought (Climate North Dakota 2018). Since North Dakota is located at the northern edge of the Great Plains and it extends from west to east. Overall, the topography of North Dakota is flat. However, the landscape in North Dakota, from the flat, fertile fields of the Red River Valley in the east to the rugged hills of the Bad Lands in the west (NDWC 2019) varies. There are some variations in climate and landscape from east to west in North Dakota. As the topography moves from east to west the type of climate condition changes from wetter to drier condition.

Discussing climate variables, temperature and precipitation are chosen because these are the most important climatic elements that directly impact with spring wheat production. A climate can change over time. This study included two consecutive time periods: the time periods were 1986-1990 and 1991-1995. Changes in temperature, precipitation, and spring wheat yield were evaluated. Daily average minimum, daily average maximum, and daily total precipitation data were gathered for growing months (June, July, and August) for nine selected weather stations. Climate and spring wheat data were gathered for ten years (from 1986 to 1995) for the nine counties.

3.1 Study Area and Site Selection

The study for this research is the State of North Dakota and nine different county areas (Figure 3.1). Site selection is based on North Dakota Agricultural Districts (Figure 3.2). This figure shows 53 counties, which are divided into nine agricultural districts. The districts are: North-West (NW), West-Central (WC), South-West (SW), North-Central (NC), Central (C), South-Central (SC), North-East (NE), East-Central (EC), and South-East (SE). The study area map was created using ArcGIS software, version 10.6.

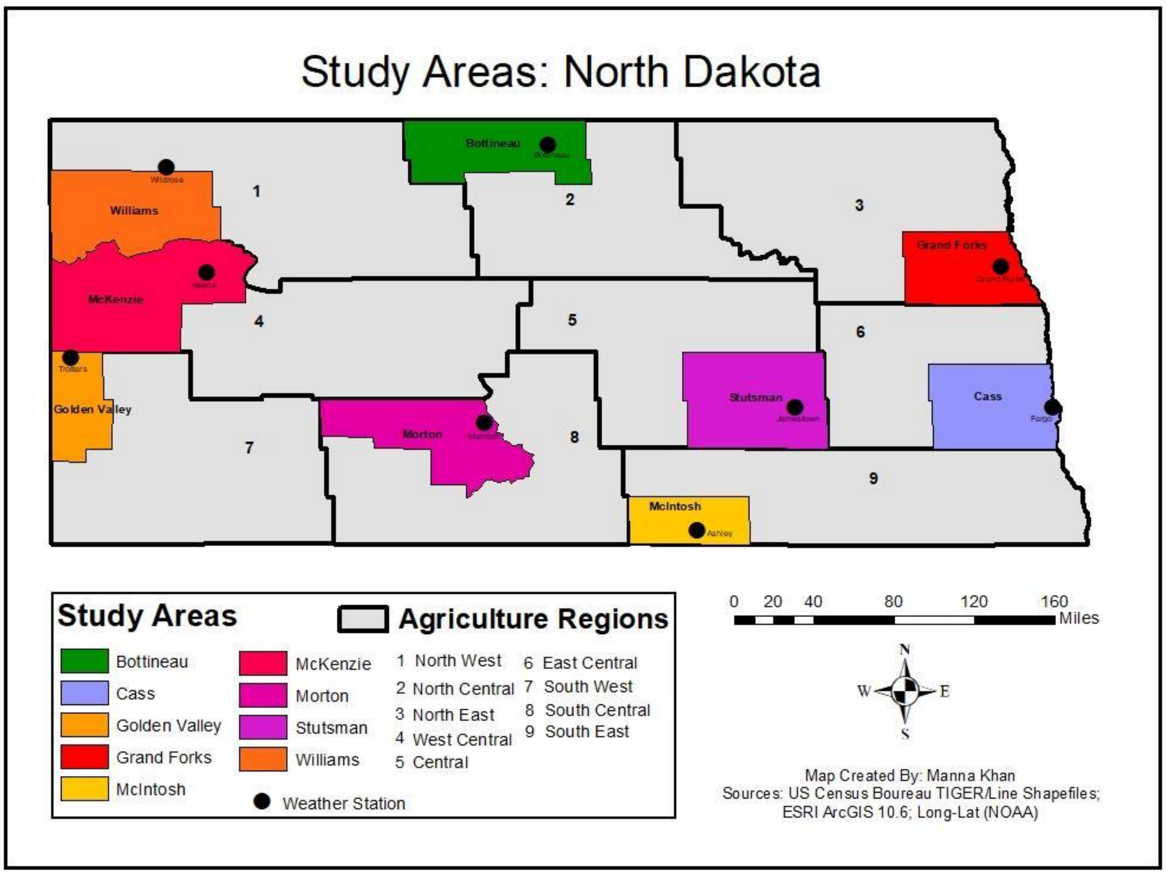

Figure 3.1 Map of North Dakota Agriculture Region: Study Areas. Sources: USDA; NOAA; ESRI; and U. S. Census Bureau.

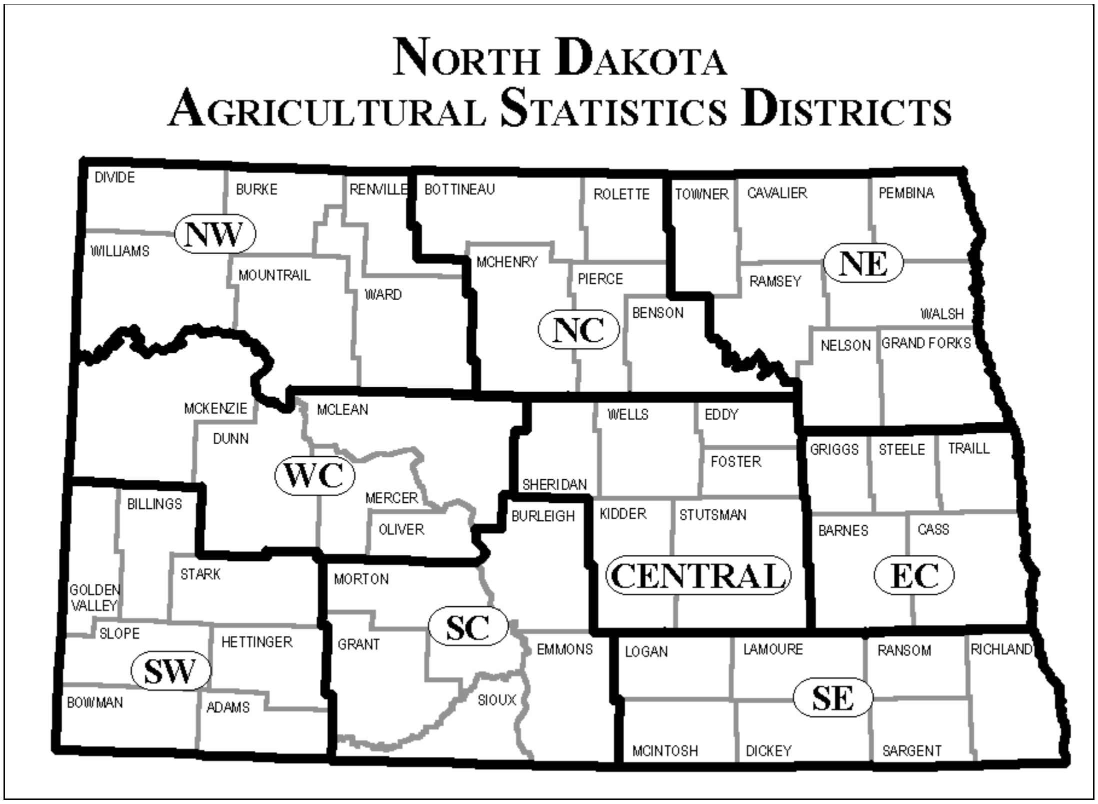

Figure 3.2 North Dakota County and Agricultural Statistics Districts. Source: USDA's National Agricultural Statistics Service.

For this study, the nine agricultural regions in the study area are adapted from the districts of Figure 3.2. While choosing the study areas, the climate data and the spring wheat data are taken into consideration. The examined climate data consisted of maximum temperature, minimum temperature, and precipitation. The examined spring wheat data consisted of acres planted, acres harvested, and bushels per acre. The sample study areas are selected in one county from each agricultural region depending on complete weather data availability. Further, the nine weather stations selected represent a complete weather record for that region shown in Figure 3.1. The nine sample counties are Bottineau, Cass, Golden Valley, Grand Forks, McIntosh, McKenzie, Morton, Stutsman, and Williams, and the weather stations representing these counties include Bottineau, Fargo, Trotters, Grand Forks International Airport, Ashley, Keene 3 S, Mandan, Jamestown, and Wildrose, respectively.

3.2 Data Collection for Temperature, Precipitation, and Spring Wheat Yield

Data were compiled for the study periods of interest 1986-1990 and 1991-1995. Data was assessed for the months of June through August for a ten year span from 1986 to 1995. The following weather data were collected from the National Oceanic and Atmospheric Administration (NOAA) website: the nine weather stations' daily average minimum temperature, daily maximum temperature, and total daily precipitation. The nine weather stations data was accessed from National Centers for Environmental Information (NCEI), NOAA's National Centers for Environmental Information hosts and provides public access for weather and climate datasets. The online available data was delivered through email without charge. Data was retrieved by daily normal, 1950 to 2010, and weather station selection was by county. Each weather station data was delivered in Excel spreadsheets, which contained daily average minimum temperature, daily average maximum temperature, and total daily precipitation.

The spring wheat yield data were obtained from the United States Department of Agriculture (USDA): National Agricultural Statistics Service (NASS) website. The HRS wheat data collected from USDA/NASS Quick Stats survey program and the North Dakota agricultural districts detailed annual data. Ten years HRS wheat data were accessed starting from the year 1986 to 1995. Specific data collected for this study were: 1) spring wheat acres planted, 2) spring wheat acres harvested, and 3) yield (bushel per acre). Figures 3.3 and 3.4 are shown in this section as an example of weather and spring wheat data collection. The growing seasons of HRS wheat are varied every year. Generally, HRS wheat growing season starts from late April and ends in early September (NDWC 2018). Figures 3.3 and 3.4 show typical North Dakota spring wheat planting and harvesting time schedules, which are indicated in the NDWC report (2018). If a region experiences colder temperatures in late April, then planting will be delayed until the

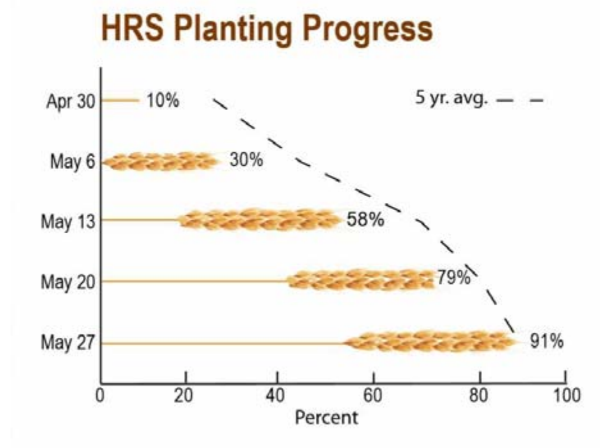

Figure 3.3 North Dakota Spring Wheat Planting Time. Source: North Dakota Wheat Commission.

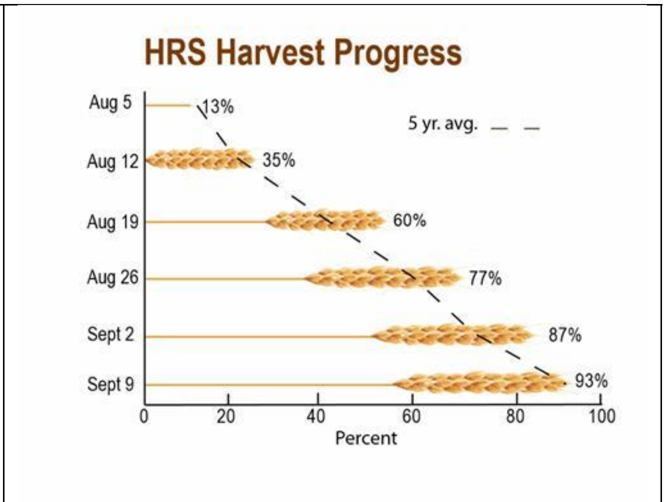

Figure 3.4 North Dakota Spring Wheat Harvesting Time. Source: North Dakota Wheat Commission.

soil warms up. Initial planting progress could be slow, but the progress accelerates rapidly in the second half of May in hot and dry weather conditions. Most of the crop is planted by late May. In some parts of the regions, low crop emergence can occur due to lack of topsoil moisture and hot temperatures. If a shift in moisture patterns with timely and plentiful rainfall occurs much of June that benefits the crop by reviving previously stressed areas and allows early growth. The average temperature and precipitation should be moderate during much of the growing season which accelerates crop maturity. As a result, the potential exists for higher crop yield.

Normal and steady harvest begins in late July and rapid harvest starts the second half of August. In most of the region, harvest usually is completed by mid-September. The late harvest, especially across northern areas and western areas, is slower due to rain and late crop ripening. Generally, warm and dry conditions are favorable for harvesting (NDWC 2018).

For this study, the data collection for temperature and precipitation were June, July, and August and fell within the growing season of HRS wheat. These months were chosen because they had complete monthly data. The month of June was selected because wheat should be planted before June 1st (Figure 3.3). The month of August was selected because most of the crop will have been harvested by end of August (Figure 3.4). The units were measured for temperature in Fahrenheit (ºF) and precipitation in inches (in). Seasonal adjustment was done for temperature values by averaging all three months daily mean temperatures. Precipitation values were summed because it didn't rain each day. The unit was measured for HRS wheat in bushels per acre (bu/acre). One bushel wheat is approximately 60 pounds (lbs.).

3.3 Statistics

Statistics were used to determine if temperatures and precipitation in the regions between the 1st period (1986-1990) and the 2nd period (1991-1995) were statistically different. Microsoft Excel and Microsoft Word were mostly used for storing, organizing, and graphing data. Additionally, Microsoft Excel was a useful tool in creating tables, climographs, and descriptive statistics, and Excel's formulas were helpful in calculating the difference of means *t*-Test and the coefficient of variation for the two time periods.

3.3.1 Descriptive Statistics

Descriptive statistics are important because they provide a concise numerical or quantitative summary of the characteristics of a data set, and it describes some important aspect of the data so it can be easily understood (McGrew, Jr., et al. 2014). The descriptive statistics correlation analysis provides a precise, quantitative set of statistical methods to measure both the direction and strength of association between a pair of spatial variables (McGrew, Jr., et al. 2014).

3.3.2 The Difference of Means t-test

The difference of means t-test is also known as Student's t-test. The purpose of a t-test is to compare the means and distributions of two different variables at once. The t-test compared two time periods' (1986-1990 and 1991-1995) averages in temperature and precipitation for nine weather stations. With this test, the values were tested to determine if the differences of the means were statistically significant. The level of significance or alpha (α) value was selected to be 1-0.95=0.05, the p-value was 1.96. The formula for test statistics:

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sigma_{\overline{X_1} - \overline{X_2}}}$$

$$\sigma_{\overline{X_1} - \overline{X_2}} = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$$

Where: $\bar{X}_1$= mean of period 1(1986-1990)

$\bar{X}_2$= mean of period 2 (1991-1995)

$\sigma_{\overline{X_1} - \overline{X_2}}$ = Standard error of the difference of means

σ^2= square root of the variance

Test statistics were used to determine if there were significant differences across the periods.

3.3.3 Coefficient of Variation (CV)

Using correlation analysis, this study examined temperatures and precipitations and their relationships between two time periods. Coefficient of variation values were statistically determined to find the degree of similarity between the temperature and the precipitation between the two periods.

Formula for coefficient of variation:

$$CV = \frac{S.D}{\bar{X}}$$

Where: CV = coefficient variation

S.D = standard deviation

$\bar{X}$ = sample mean

3.4 Graphs

Climographs were created to analyze seasonal temperature and precipitation patterns for two time periods. Ninety climographs were created using ten years of daily temperature and precipitation data for the nine weather stations to show seasonal temperature and precipitation patterns. Nine climographs were created to demonstrate yearly temperature and precipitation trends during 1986-1995.

In addition, 18 line graphs were created for the nine weather stations to display spring wheat yield in relation to temperature and precipitation. The graphs were created using Microsoft Excel software. The units used were ºF for temperature, inches for precipitation, and bushel per acre (bu/acre) for spring wheat yield.

3.5 Limitation

Complete weather station data for temperature and precipitation for 53 counties was challenging. Since each county does not have complete weather data, one weather station per agricultural region was selected. The counties in each agricultural district were represented by a sole weather station as to foster similar area comparisons throughout the study.

CHAPTER 4

RESULTS

This chapter highlights the tables, climographs, and graphs that illustrate a ten-year trend of temperature and precipitation and their relationship with spring wheat yield. The results give an idea of which regions in North Dakota have experienced more drought conditions than others, which regions have received more precipitation than others, and how the weather conditions and location influence spring wheat yield. Having these results, it is possible to recognize the bumper crop and scarce crop years of spring wheat yield, the drought and wet years, and the counties spring wheat yield in terms of temperature and precipitation. For each of the weather stations, the sample size was n=460, the degrees of freedom was df =459, and the level of confidence was 1-α= 95%.

Nine weather stations' detailed descriptive statistics for temperature and precipitation are shown in Appendix B. As noted earlier, Figure 3.1 shows the map of North Dakota agriculture region study areas. The research study areas comprise nine different regions used to investigate if temperature and precipitation have any relationship to spring wheat yield. For analytical purposes, North Dakota's nine agricultural areas are separated into three distinct sections divided from north to south: eastern North Dakota, central North Dakota, and western North Dakota. Eastern North Dakota includes Grand Forks, Cass, and McIntosh Counties. Central North Dakota includes Bottineau, Stutsman, and Morton Counties. Western North Dakota includes Williams, McKenzie, and Golden Valley Counties.

4.1 Eastern North Dakota: Grand Forks County (Grand Forks), Cass County (Fargo International Airport), McIntosh County (Ashley)

4.1.1 Temperature

Table 4.1 shows eastern North Dakota's maximum temperatures for the 1st period (1986-1990) and the 2nd period (1991-1995). The descriptive statistics consisted of minimum temperature, maximum temperature, range, mean, median, mode, variance, and standard deviation for three weather stations: Grand Forks, Fargo, and Ashley. The maximum temperatures recorded for Grand Forks were 104 ºF, Fargo 106 ºF, and Ashley 106 ºF in the 1st period, and 100 ºF, 100 ºF, and 99 ºF, respectively, in the 2nd period. In the 1st period, the means calculated for Grand Forks were 81.3 ºF, Fargo 82.6 ºF, and Ashley 82.6 ºF, and 77.9 ºF, 78.8 ºF, and 77.0 ºF, respectively, in the 2nd period. The standard deviations were calculated for Grand Forks 8.09, Fargo 8.35, and Ashley 9.12 for the 1st period, and 8.11, 7.74, and 8.28, respectively, for the 2nd period.

Eastern North Dakota	Temperature Maximum (°F)								Temperature Maximum (°F)							
	1st Period: 1986-1990								2st Period: 1991-1995							
Weather Stations	Min	Max	Rang	Mean	Medi	Mode	Vari	Std.D	Min	Max	Rang	Mean	Medi	Mode	Vari	Std.D
Grand Forks	55	104	49	81.32	82	82	65.49	8.09	54	100	46	77.93	78	80	65.7	8.11
Fargo	56	106	50	82.6	83	82	69.72	8.35	55	100	45	78.82	79	79	59.84	7.74
Ashley	53	106	53	82.56	83	85	83.14	9.12	51	99	48	77.04	78	78	68.62	8.28

Table 4.1 Descriptive Statistics for Eastern North Dakota of Maximum Temperature for 1st and 2nd Periods. Source: NOAA.

The lower value of test statistics indicates there is not a significant difference in temperature or precipitation between the periods. The test critical two-tail value is 1.96, which always will be constant. Tables 4.2, 4.3, and 4.4 show the difference of means of maximum temperatures for Grand Forks, Fargo, and Ashley correspondingly for 1986-1990 and 1991-1995.

Table 4.2 shows the difference of means of maximum temperatures for Grand Forks for the years 1986-1990 and 1991-1995; the test statistic (calculated) was 6.35. The test statistic value was higher than 1.96, so the null hypothesis is rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table, 6.35 > 1.96.

Grand Forks (Grand Forks)	*Tmax 1st period*	*Tmax 2nd period*
Mean	81.32	77.93
Variance	65.49	65.70
Observations	460.00	460.00
Pearson Correlation	0.00	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	6.35	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.2 Maximum Temperature for Grand Forks Difference of Means.
Source: NOAA.

Table 4.3 shows the difference of means of maximum temperatures for Fargo for the years 1986-1990 and 1991-1995. The test statistic (calculated) was 6.78. The test statistic value was higher than 1.96, so the null hypothesis is rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table, 6.78 > 1.96.

Cass (Fargo)	*Tmax 1st period*	*Tmax 2nd period*
Mean	82.60	78.82
Variance	69.72	59.84
Observations	460.00	460.00
Pearson Correlation	-0.10	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	6.78	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.3 Maximum Temperature for Fargo Difference of Means. Source: NOAA.

Table 4.4 shows the difference of means of maximum temperatures for Ashley for the years 1986-1990 and 1991-1995. The test statistic (calculated) was 9.62. The test statistic value was higher than 1.96, so the null hypothesis is rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table, 9.62 > 1.96.

McIntosh (Ashley)	*Tmax 1st period*	*Tmax 2nd period*
Mean	82.56	77.04
Variance	83.14	68.62
Observations	460.00	460.00
Pearson Correlation	0.00	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	9.62	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.4 Maximum Temperature for Ashley Difference of Means. Source: NOAA

The coefficient of variation (CV) compares variability between two periods of maximum temperatures and precipitation data set on a ratio scale. Table 4.5 shows Grand Forks' maximum temperature of CV in the 1st period was 9.95% and in the 2nd period was 10.40%. The CV of precipitation in the 1st period was 289.65% and in the 2nd period was 296.01%.

Grand Forks Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	81.3	0.08	Mean	77.93	0.13
S.D	8.09	0.23	S.D	8.11	0.39
Variance	65.5	0.05	Variance	65.70	0.15
CV (%)	9.95	289.65	CV (%)	10.40	296.01
CV	0.10	2.90	CV	0.10	2.96

Table 4.5 Coefficient of Variation: Grand Forks, Maximum Temperature and Precipitation. Source: NOAA.

Table 4.6 shows Fargo maximum temperature of CV in the 1st period was 10.11% and in the 2nd period was 9.81%. The CV of precipitation in the 1st period was 307.20% and in the 2nd period was 313.83%.

Fargo Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	82.60	0.08	Mean	78.82	0.11
S.D	8.35	0.25	S.D	7.74	0.36
Variance	69.72	0.06	Variance	59.84	0.13
CV (%)	10.11	307.20	CV (%)	9.81	313.83
CV	0.10	3.07	CV	0.10	3.14

Table 4.6 Coefficient of Variation: Fargo, Maximum Temperature and Precipitation. Source: NOAA.

Table 4.7 shows Ashley maximum temperature of CV in the 1st period was 11.04% and in the 2nd period was10.75%. The CV of precipitation in the 1st period was 323.50% and in the 2nd period was 275.63%.

Ashley Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	82.56	0.08	Mean	77.04	0.12
S.D	9.12	0.27	S.D	8.28	0.34
Variance	83.14	0.07	Variance	68.62	0.12
CV (%)	11.04	323.50	CV (%)	10.75	275.63
CV	0.11	3.23	CV	0.11	2.76

Table 4.7 Coefficient of Variation: Ashley, Maximum Temperature and Precipitation. Source: NOAA.

Figure 4.1 shows a climograph with a ten-year span of temperature and precipitation trends for Grand Forks. In 1988, the highest average maximum temperature recorded for Grand Forks was 85.1ºF. In 1992, the lowest average minimum temperature recorded was 51.08ºF. In 1993, during the months of June, July, and August, the highest precipitation received was 16.98 inches. In 1989, the lowest precipitation received was 5.22 inches.

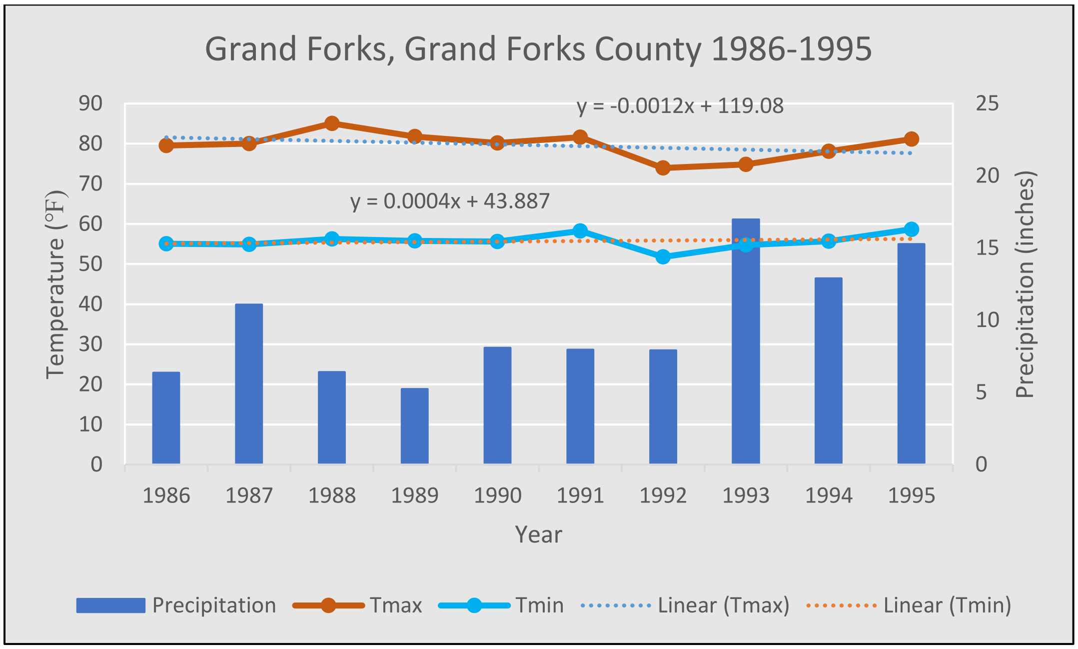

Figure 4.1 Climograph of Temperature and Precipitation Trends for Grand Forks. Source: NOAA.

Figure 4.2 shows a climograph with a ten-year span of temperature and precipitation trends for Fargo. In 1988, the highest average maximum temperature recorded was 87.5ºF. In 1992, the lowest average minimum temperature recorded was 52.06ºF. In 1993, during the months of June, July, and August, the highest precipitation received was 13.12 inches. In 1988, the lowest temperature received was 3.84 inches.

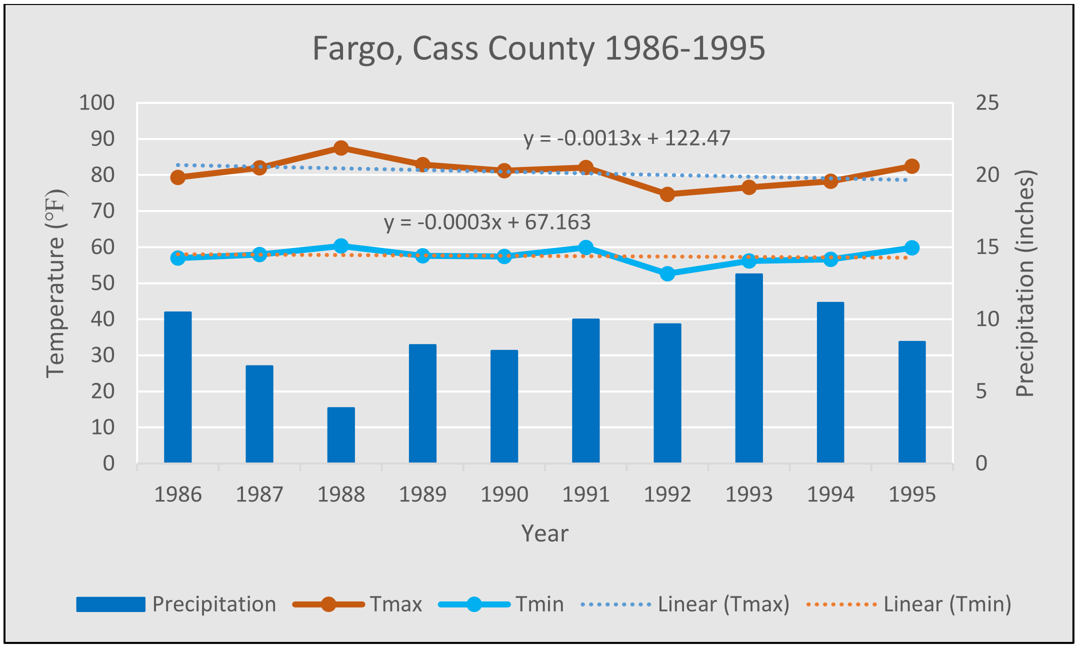

Figure 4.2 Climograph of Temperature and Precipitation Trends for Fargo.
Source: NOAA.

Figure 4.3 shows a climograph with a ten-year span of temperature and precipitation trends for Ashley. In 1988, the highest average maximum temperature recorded was 87.9ºF. In 1992, the lowest average minimum temperature recorded was 50.02ºF. In 1993, during the months of June, July, and August, the highest precipitation received was 20.51 inches of precipitation. In 1988, the lowest precipitation received was 3.69 inches.

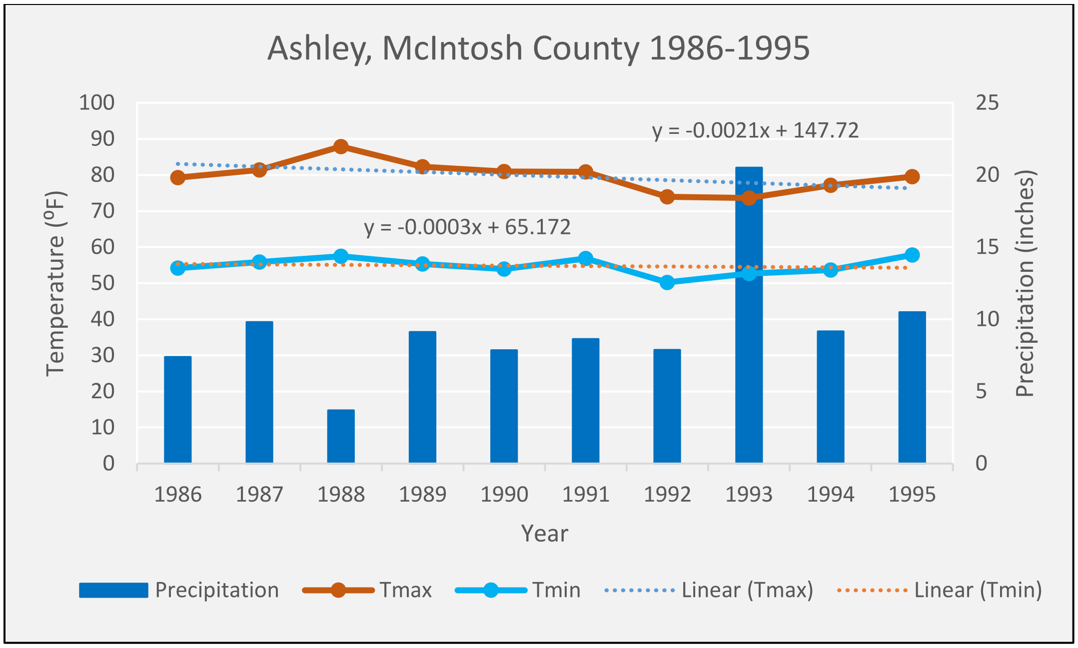

Figure 4.3 Climograph of Temperature and Precipitation Trends for Ashley.
Source: NOAA.

4.1.2 Precipitation

Table 4.8 shows Eastern North Dakota's descriptive statistics of precipitation for the1st period and the 2nd period. The descriptive statistics included maximum precipitation, sum, variance, and standard deviation for three weather stations: Grand Forks, Fargo, and Ashley. The maximum precipitation recorded for Grand Forks were 2.45 inches, Fargo 1.92 inches, and Ashley 2.70 inches in the 1st period. The maximum precipitation recorded for Grand Forks was 4.44 inches, Fargo 4.42 inches, and Ashley 3.06 inches in the 2st period. In the 1st period, the sum calculated for Grand Forks were 37.17 inches, Fargo 37.09 inches, and Ashley 37.93 inches. In the 2nd period, the sum calculated for Grand Forks was 61.01 inches, Fargo 52.33 inches, 56.64 inches. The standard deviations calculated were Grand Forks 0.23, Fargo 0.25, and Ashley 0.27 for the1st period. The standard deviations calculated were Grand Forks 0.39, Fargo 0.36, and Ashley 0.34 for the 2st period.

Eastern North Dakota	Precipitation (Inches)								Precipitation (inches)							
	1st Period: 1986-1990								2nd Period: 1991-1995							
Weather Stations	Min	Max	Rang	Mean	Sum	Mode	Vari	Std.D	Min	Max	Rang	Mean	Sum	Mode	Vari	Std.D
Grand Forks	0	2.45	2.45	0.08	37.17	0	0.05	0.23	0	4.44	4.44	0.13	61.01	0	0.15	0.39
Fargo	0	1.92	1.92	0.08	37.09	0	0.06	0.25	0	4.42	4.42	0.11	52.33	0	0.13	0.36
Ashley	0	2.7	2.7	0.08	37.93	0	0.07	0.27	0	3.06	3.06	0.12	56.64	0	0.12	0.34

Table 4.8 Descriptive Statistics for Eastern North Dakota of Precipitation for 1st and 2nd Periods. Source: NOAA.

Tables 4.9, 4.10, and 4.11 show the difference of means in precipitation for Grand Forks, Fargo, and Ashley correspondingly for 1986-1990 and 1991-1995. Table 4.9 shows the difference of means in precipitation for Grand Forks during the years 1986-1990 and 1991-1995. The test statistic (calculated) was -2.39. The Grand Forks weather station's test statistic value was less than -1.96, so the null hypothesis was rejected. As seen in the table below, -2.39 < -1.96. This means there is a significant difference in precipitation between the two periods in the study.

Grand Forks (Grand Forks)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.08	0.13
Variance	0.05	0.15
Observations	460.00	460.00
Pearson Correlation	-0.04	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-2.39	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.02	
t Critical two-tail	1.96	

Table 4.9 Precipitation for Grand Forks Difference of Means. Source: NOAA.

Table 4.10 shows the difference of means in precipitation for Fargo during the years 1986-1990 and 1991-1995. The test statistic (calculated) was -1.61. The Fargo weather station's test statistic value was greater than -1.96, so the null hypothesis was not rejected. As seen in the table below,

-1.61 > -1.96. This means there is not a significant difference in precipitation between the two periods in the study.

Cass (Fargo)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.08	0.11
Variance	0.06	0.13
Observations	460.00	460.00
Pearson Correlation	-0.04	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-1.61	
P(T<=t) one-tail	0.05	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.11	
t Critical two-tail	1.96	

Table 4.10 Precipitation for Fargo Difference of Means. Source: NOAA.

Table 4.11 shows the difference of means in precipitation for Ashley during the years 1986-1990 and 1991-1995. The test statistic (calculated) was -1.99. The Ashley weather station's test statistic value was less than -1.96, so the null hypothesis was rejected. As seen in the table below, -1.99 < -1.96. This means there is a significant difference in precipitation between the two periods in the study.

McIntosh (Ashley)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.08	0.12
Variance	0.07	0.12
Observations	460.00	460.00
Pearson Correlation	-0.03	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-1.99	
P(T<=t) one-tail	0.02	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.05	
t Critical two-tail	1.96	

Table 4.11 Precipitation for Ashley Difference of Means. Source: NOAA

4.1.3 Spring Wheat Yield

Figures 4.4, 4.5, and 4.6 show graphs comparing maximum temperature and spring wheat yield for Grand Forks, Cass, and McIntosh counties, respectively. The spring wheat yield is measured in bushels per acre (bu/acre). Figure 4.4 shows a graph comparing average maximum temperature and spring wheat yield for Grand Forks County. In 1988, the average maximum temperature was 85.1ºF, and the spring wheat yield was 26.7 bu/acre. In 1990, the average maximum temperature was 80.2ºF, and the spring wheat yield was 49.5 bu/acre. In 1993, the average maximum temperature was 73.9ºF, and the spring wheat yield was 54.7 bu/acre.

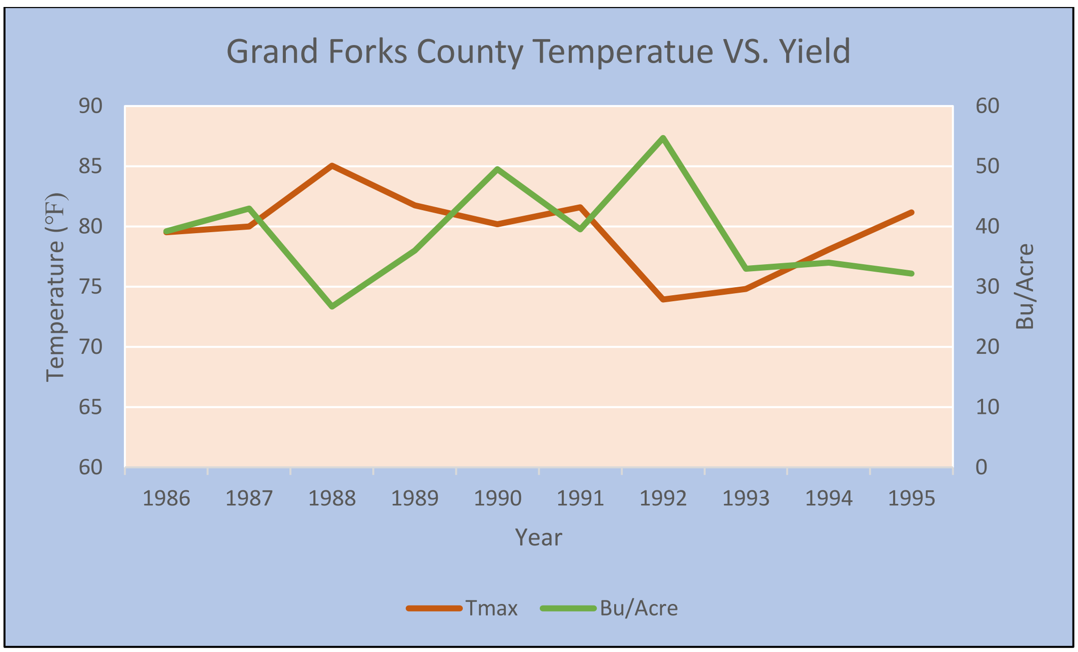

Figure 4.4 Graph Comparing Maximum Temperature and Spring Wheat Yield for Grand Forks County. Sources: NOAA and USDA.

Figure 4.5 shows a graph comparing average maximum temperature and spring wheat yield for Cass County. In 1988, the average maximum temperature was 87.5ºF, and the spring wheat yield was 19.1 bu/acre. In 1990, the average maximum temperature was 81.2ºF, and the spring wheat yield was 40.5 bu/acre. In 1993, the average maximum temperature was 76.6ºF and the spring wheat yield was 32.3 bu/acre.

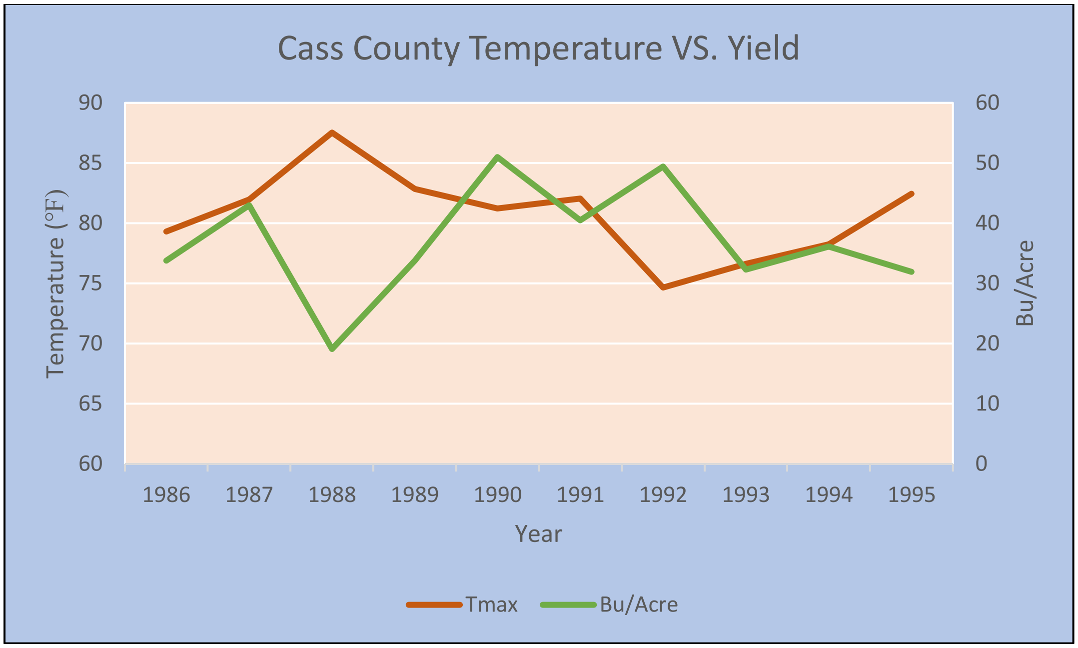

Figure 4.5 Graph Comparing Maximum Temperature and Spring Wheat Yield for Cass County. Sources: NOAA and USDA.

Figure 4.6 shows a graph comparing average maximum temperature and spring wheat yield for McIntosh County. In 1988, the average maximum temperature was 87.9ºF, and the spring wheat yield was 6 bu/acre. In 1990, the average maximum temperature was 81ºF, and the spring wheat yield was 20 bu/acre. In 1993, the average maximum temperature was 73.6ºF, and the spring wheat yield was 21.3 bu/acre.

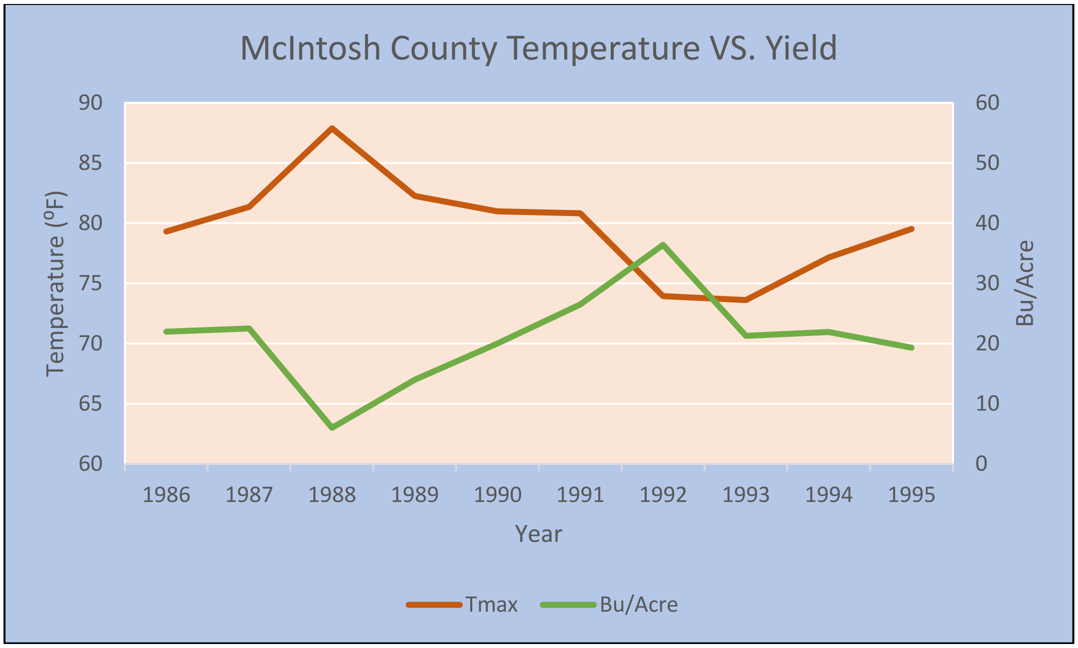

Figure 4.6 Graph Comparing Maximum Temperature and Spring Wheat Yield for McIntosh County. Sources: NOAA and USDA.

Figures 4.7, 4.8, and 4.9 show graphs comparing precipitation and spring wheat yield for Grand Forks, Cass, and McIntosh counties, respectively. Figure 4.7 shows a graph comparing total precipitation and spring wheat yield for Grand Forks County. In 1988, the precipitation was 6.41 inches, and the spring wheat yield was 26.7 bu/acre. In 1990, the precipitation was 8.09 inches, and the spring wheat yield was 49.5 bu/acre. In 1993, the precipitation was 16.93 inches, and the spring wheat yield was 33 bu/acre.

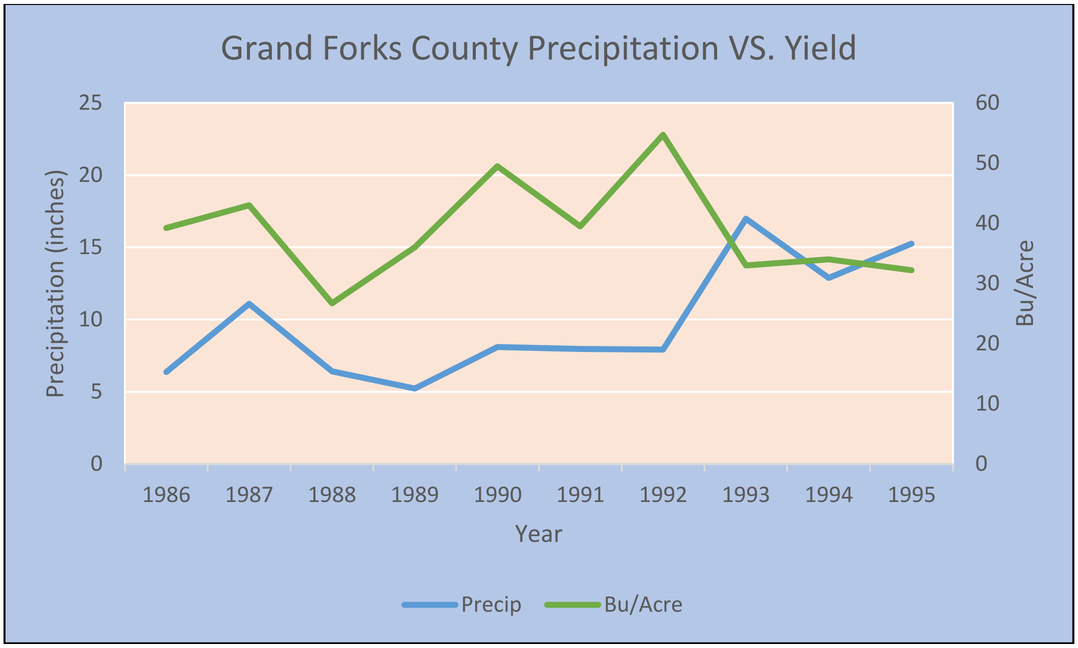

Figure 4.7 Graph Comparing Precipitation and Spring Wheat yield for Grand Forks County. Sources: NOAA and USDA.

Figure 4.8 shows a graph comparing total precipitation and spring wheat yield for Cass County. In 1988, the precipitation was 3.84 inches, and the spring wheat yield was 19.1 bu/acre. In 1990, the precipitation was 7.82 inches, and the spring wheat yield was 51 bu/acre. In 1993, the precipitation was 13.12 inches, and the spring wheat yield was 32.3 bu/acre.

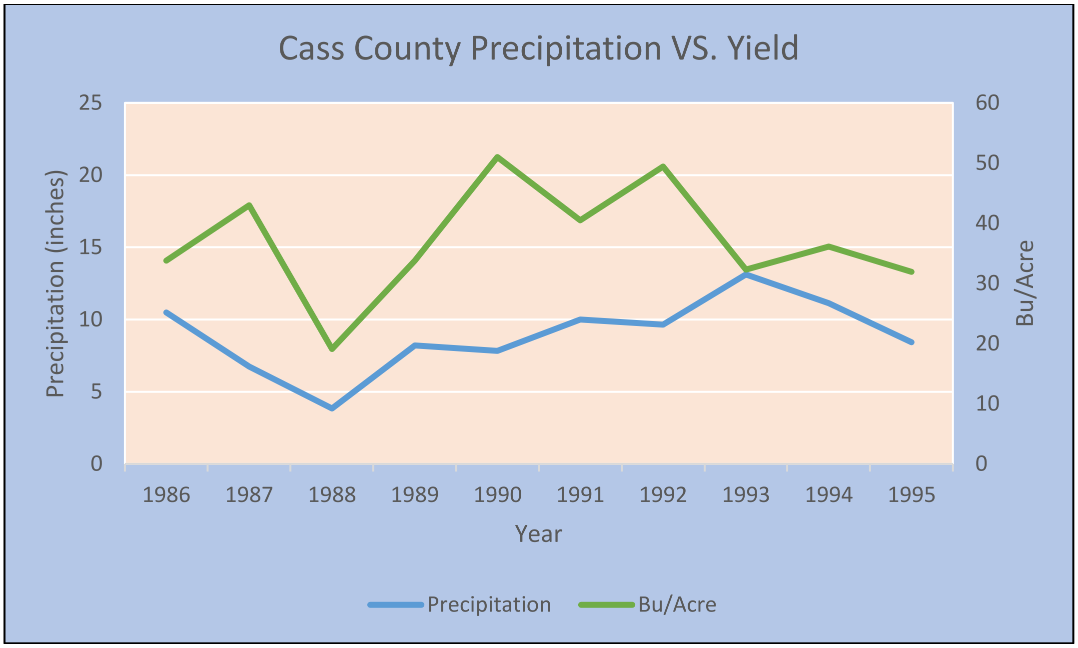

Figure 4.8 Graph Comparing Precipitation and Spring Wheat Yield for Cass County.
Sources: NOAA and USDA.

Figure 4.9 shows a graph comparing total precipitation and spring wheat yield for McIntosh County. In 1988, the precipitation was 3.69 inches and the spring wheat yield was 6 bu/acre. In 1990, the precipitation was 7.84 inches and the spring wheat yield was 20 bu/acre. In 1993, the precipitation was 20.51 inches and the spring wheat yield was 21.3 bu/acre.

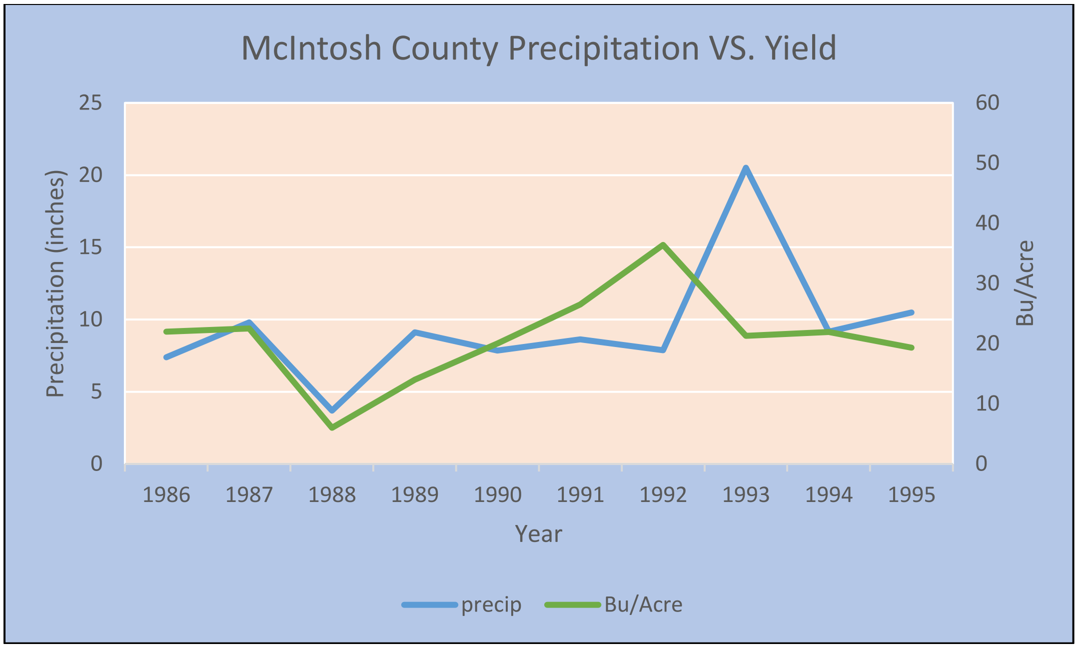

Figure 4.9 Graph Comparing Precipitation and Spring Wheat Yield for McIntosh County. Sources: NOAA and USDA.

4.2 Central North Dakota: Bottineau County (Bottineau), Stutsman County (Jamestown), and Morton County (Mandan)

4.2.1 Temperature

Table 4.12 displays central North Dakota's maximum temperatures for the 1st period and the 2nd period. The descriptive statistics consisted of minimum temperature, maximum temperature, range, mean, median, mode, variance, and standard deviation for three weather stations: Bottineau, Jamestown, and Mandan. The maximum temperatures recorded for Bottineau were 100ºF, Jamestown 108ºF, Mandan 105ºF in the 1st period; and 98ºF, 100ºF, and 103ºF, respectively, in the 2nd period. In the 1st period, the means calculated for Bottineau were 79.31ºF, Jamestown 83.59ºF, and Mandan 82.28ºF; and 75.95ºF, 78.12ºF, and 78.47ºF, respectively, in the 2nd period. The standard deviations included Bottineau 9.24, Jamestown 8.70, and Mandan 9.50 for 1st the period. The standard deviations calculated for Bottineau were 8.41, Jamestown 8.71, and Mandan 9.08 for the 2nd period as seen below.

Central North Dakota	Temperature Maximum (°F)								Temperature Maximum (°F)							
	1st Period: 1986-1990								2st Period: 1991-1995							
Weather Stations	Min	Max	Rang	Mean	Medi	Mode	Vari	Std.D	Min	Max	Rang	Mean	Medi	Mode	Vari	Std.D
Bottineau	45	100	55	79.31	79	85	85.41	9.24	50	98	48	75.95	76	79	70.66	8.41
Jamestown	55	108	53	83.59	84	87	75.67	8.7	53	100	47	78.12	79	83	75.92	8.71
Mandan	54	105	51	82.28	82	80	90.23	9.5	51	103	52	78.47	79	77	82.37	9.08

Table 4.12 Descriptive Statistics for Central North Dakota of Maximum Temperature for 1st and 2nd periods. Source: NOAA.

Tables 4.13, 4.14, and 4.15 show the difference of means of maximum temperatures for Bottineau, Jamestown, and Mandan for 1986-1990 and 1991-1995. Table 4.13 shows the difference of means of maximum temperatures for Bottineau for the years 1986-1990 and 1991-1995. The test statistic (calculated) was 5.75. The test statistic value was higher than 1.96, so the null hypothesis was rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table, 5.75 > 1.96 as seen below.

Bottineau (Bottineau)	*Tmax 1st period*	*Tmax 2nd period*
Mean	79.31	75.95
Variance	85.41	70.66
Observations	460.00	460.00
Pearson Correlation	-0.01	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	5.75	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.13 Maximum Temperature for Bottineau Difference of Means. Source: NOAA.

Table 4.14 shows the difference of means of maximum temperatures for Jamestown for the years 1986-1990 and 1991-1995. The test statistic (calculated) was 9.33. The test statistic value was higher than 1.96, so the null hypothesis was rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table, 9.33 > 1.96, as seen below.

Stutsman (Jamestown)	*Tmax 1st period*	*Tmax 2nd period*
Mean	83.59	78.12
Variance	75.67	75.92
Observations	460.00	460.00
Pearson Correlation	-0.04	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	9.33	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.14 Maximum Temperature for Jamestown Difference of Means. Source: NOAA.

Table 4.15 shows the difference of means of maximum temperatures for Mandan for the years 1986-1990 and 1991-1995. The test statistic (calculated) was 6.24. The test statistic value was higher than 1.96, so the null hypothesis was rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table, 6.24 > 1.96, as seen below.

Morton(Mandan)	*Tmax 1st period*	*Tmax 2nd period*
Mean	82.28	78.47
Variance	90.23	82.37
Observations	460.00	460.00
Pearson Correlation	0.01	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	6.24	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.15 Maximum Temperature for Mandan Difference of Means. Source: NOAA.

Table 4.16 shows Bottineau maximum temperature of CV in the 1st period was 11.65% and in the 2nd period was11.07%. The CV of precipitation for the 1st period was 303.23% and in the 2nd period was 221.32% as seen below.

Bottineau Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	79.31	0.09	Mean	75.95	0.10
S.D	9.24	0.28	S.D	8.41	0.22
Variance	85.41	0.08	Variance	70.66	0.05
CV (%)	11.65	303.23	CV (%)	11.07	221.32
CV	0.12	3.03	CV	0.11	2.21

Table 4.16 Coefficient of Variation: Bottineau, Maximum Temperature and Precipitation. Source: NOAA.

Table 4.17 shows Jamestown maximum temperature of CV in the 1st period was 10.41% and in the 2nd period was 11.15%. The CV of precipitation for the 1st period was 356.18% and in the 2nd period was 338.02% as seen below.

Jamestown Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	83.59	0.08	Mean	78.12	0.12
S.D	8.70	0.21	S.D	8.71	0.42
Variance	75.67	0.05	Variance	75.92	0.18
CV (%)	10.41	256.18	CV (%)	11.15	338.02
CV	0.10	2.56	CV	0.11	3.38

Table 4.17 Coefficient of Variation: Jamestown, Maximum Temperature and Precipitation. Source: NOAA.

Table 4.18 shows Mandan maximum temperature of CV in the 1st period was 11.54% and in the 2nd period was 11.57%. The CV of precipitations for 1st the period was 293.10% and in the 2nd period was 294.55% as seen below.

Mandan Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	82.28	0.09	Mean	78.47	0.11
S.D	9.50	0.25	S.D	9.08	0.32
Variance	90.23	0.06	Variance	82.37	0.10
CV (%)	11.54	293.10	CV (%)	11.57	294.55
CV	0.12	2.93	CV	0.12	2.95

Table 4.18 Coefficient of Variation: Mandan, Maximum Temperature and Precipitation. Source: NOAA.

Figure 4.10 shows a climograph with a ten-year span of temperature and precipitation trends for Bottineau. In 1988, the highest average maximum temperature recorded for Bottineau was 84.4ºF. In 1992, the lowest average minimum temperature recorded was 49.2ºF. In 1993, during the months of June, July and August the highest precipitation received was 12.56 inches. In 1992, the lowest precipitation received was 4.73 inches as seen below.

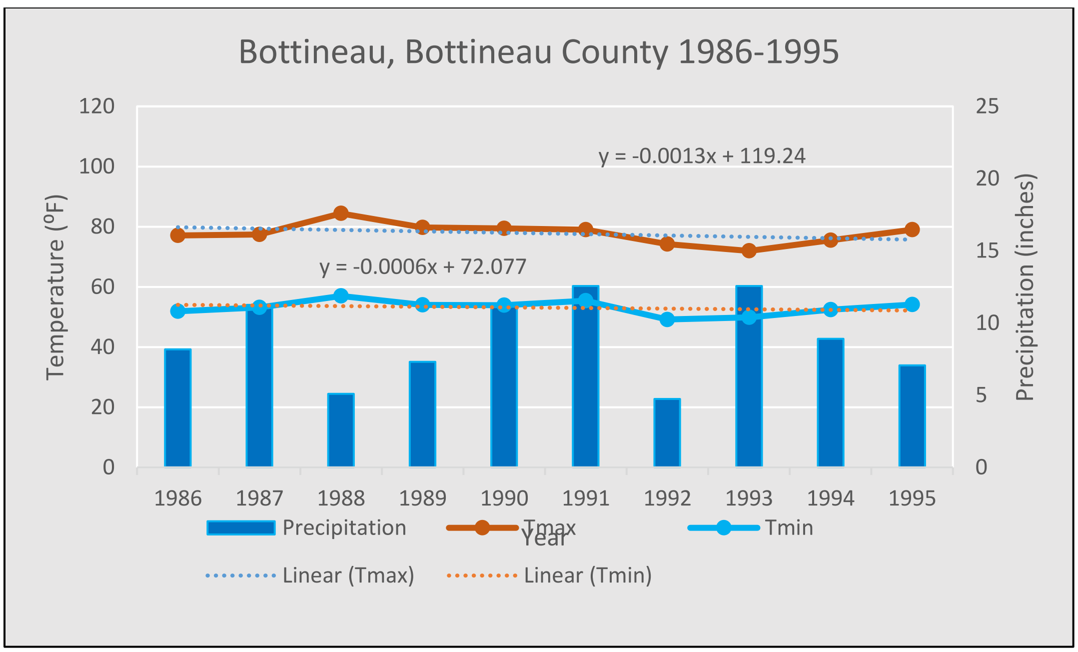

Figure 4.10 Climograph of Temperatures and Precipitation Trends for Bottineau. Source: NOAA.

Figure 4.11 shows a climograph with a ten-year span of temperature and precipitation trends for Jamestown. In 1988, the highest average maximum temperature recorded for Jamestown was

88ºF. In 1992, the lowest average minimum temperature recorded was 50.4ºF. In 1993, during the months of June, July and August the highest precipitation received was 20.8 inches. In 1988, the lowest precipitation received was 4.8 inches as seen below.

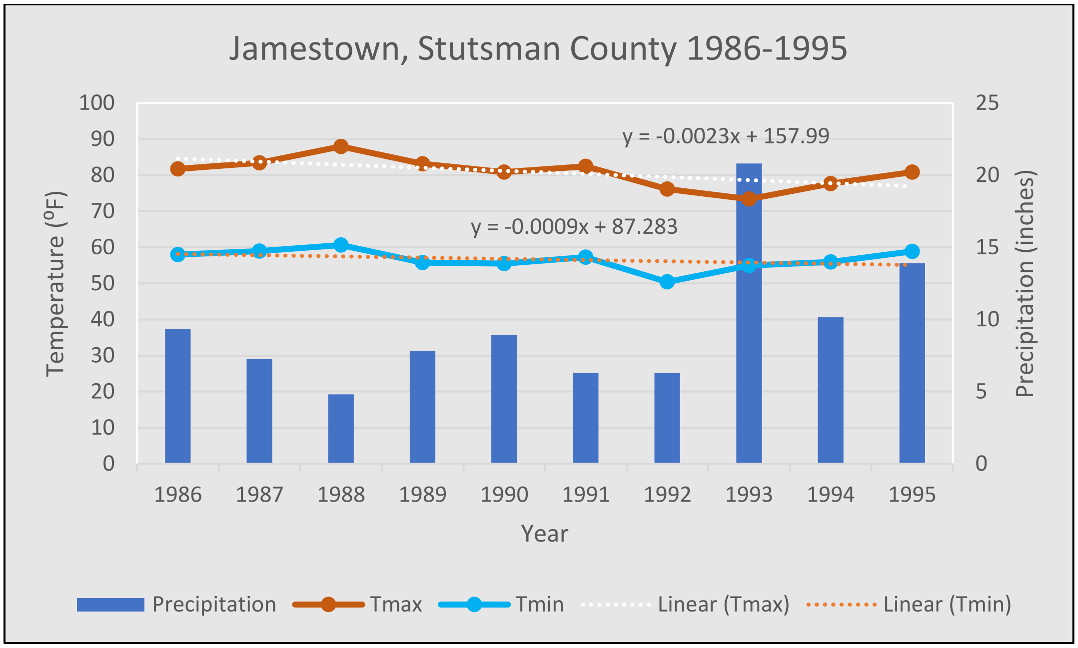

Figure 4.11 Climograph of Temperature and Precipitation Trends for Jamestown. Source: NOAA

Figure 4.12 shows a climograph with a ten-year span of temperature and precipitation trends for Mandan. In 1988, the highest average maximum temperature recorded for Mandan was 87.5ºF. In 1992, the lowest average minimum temperature recorded was 51.1ºF. In 1993, during the months of June, July, and August, the highest precipitation received was 19.79 inches. In 1987, the lowest precipitation received was 3.28 inches as seen below.

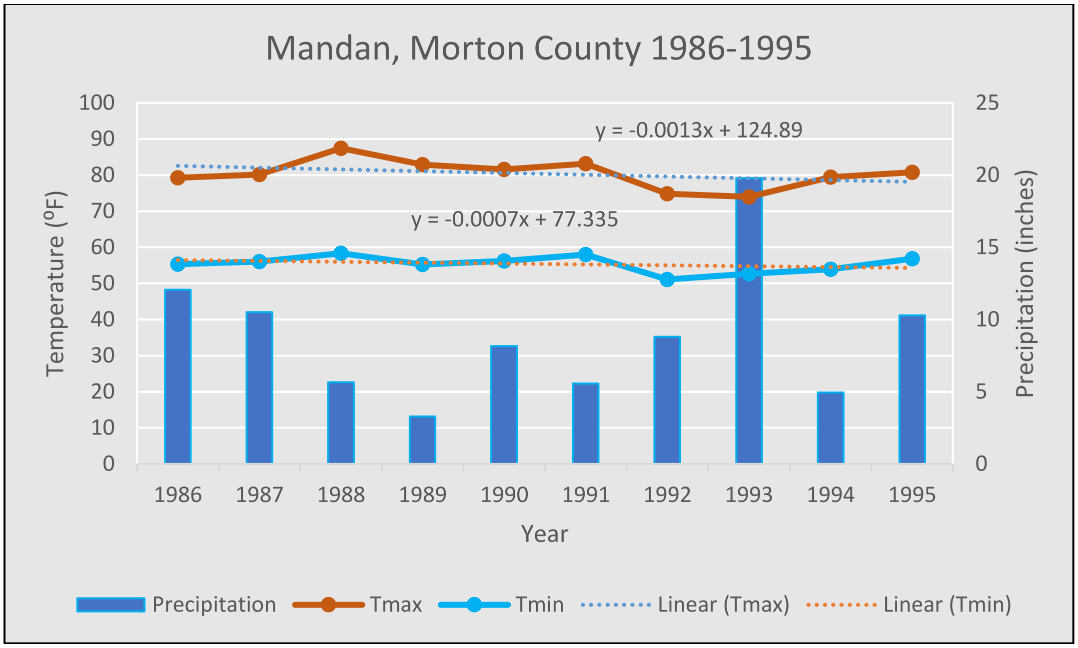

Figure 4.12 Climograph of Temperature and Precipitation Trends for Mandan Source: NOAA.

4.2.2 Precipitation

Table 4.19 shows central North Dakota's descriptive statistics of precipitation for the 1st period and the 2nd period. The descriptive statistics included maximum precipitation, sum, variance, and standard deviation for three weather stations: Bottineau, Jamestown, and Mandan. The maximum precipitation recorded for Bottineau were 2.94 inches, Jamestown 1.93 inches, Mandan 1.97 inches for the 1st period. The maximum precipitation recorded for Bottineau was 1.62 inches, Jamestown 6.35 inches, Mandan 4.25 inches in the 2st period. In the 1st period, the sums calculated: Bottineau 42.96 inches, Jamestown 38.38 inches, and Mandan 39.64 inches. In the 2nd period, the sums calculated were for 45.82 inches, and 57.41 inches, 49.40 inches, respectively. The standard deviations calculated for Bottineau were 0.28, Jamestown 0.21, and Mandan 0.25 for the 1st period, and the standard deviations for the second period were Bottineau 0.22, Jamestown 0.42, and Mandan 0.32.

Central North Dakota	Precipitation (Inches) 1st Period: 1986-1990								Precipitation (inches) 2nd Period: 1991-1995							
Weather Stations	Min	Max	Rang	Mean	Sum	Mode	Vari	Std.D	Min	Max	Rang	Mean	Sum	Mode	Vari	Std.D
Bottineau	0	2.94	2.94	0.09	42.96	0	0.08	0.28	0	1.62	1.62	0.1	45.82	0	0.049	0.22
Jamestown	0	1.93	1.93	0.08	38.38	0	0.05	0.21	0	6.35	6.35	0.12	57.41	0	0.18	0.42
Mandan	0	1.97	1.97	0.09	39.64	0	0.06	0.25	0	4.25	4.25	0.11	49.4	0	0.1	0.32

Table 4.19 Descriptive Statistics for Eastern North Dakota of Precipitation for 1st and 2nd Periods. Source: NOAA.

Tables 4.20, 4.21, and 4.22 show the difference of means in precipitation for Bottineau, Jamestown, and Mandan correspondingly for 1986-1990 and 1991-1995. Table 4.20 shows the difference of means in precipitation for Bottineau during the years 1986-1990 and 1991-1995 the test statistic (calculated) was -0.36. The Bottineau weather station's test statistic value was greater than -1.96, so the null hypothesis was not rejected, as seen in the table, -0.36 > -1.96. This means there is not a significant difference in precipitation between the two periods in the study.

Bottineau (Bottineau)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.09	0.10
Variance	0.08	0.05
Observations	460.00	460.00
Pearson Correlation	-0.06	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-0.36	
P(T<=t) one-tail	0.36	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.72	
t Critical two-tail	1.96	

Table 4.20 Precipitation for Bottineau Difference of Means. Source: NOAA.

Table 4.21 shows the difference of means in precipitation for Jamestown during the years 1986-1990 and 1991-1995. The test statistic (calculated) was -1.85. The Jamestown weather station's test statistic value was greater than -1.96, so the null hypothesis was not rejected, as seen in the table below, -1.85 > -1.96. This means there is not a significant difference in precipitation between the two periods in the study.

Stutsman (Jamestown)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.08	0.12
Variance	0.05	0.18
Observations	460.00	460.00
Pearson Correlation	-0.03	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-1.85	
P(T<=t) one-tail	0.03	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.06	
t Critical two-tail	1.96	

Table 4.21 Precipitation for Jamestown Difference of Means. Source: NOAA.

Table 4.22 shows the difference of means in precipitation for Mandan during the years 1986-1990 and 1991-1995. The test statistic (calculated) was -1.10. The Mandan weather station's test statistic value was greater than -1.96, so the null hypothesis is not rejected, as seen in the table below, -1.10 > -1.96. This means there is not a significant difference in precipitation between the two periods in the study.

Morton(Mandan)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.09	0.11
Variance	0.06	0.10
Observations	460.00	460.00
Pearson Correlation	-0.05	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-1.10	
P(T<=t) one-tail	0.14	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.27	
t Critical two-tail	1.96	

Table 4.22 Precipitation for Mandan Difference of Means. Source: NOAA.

4.2.3 Spring Wheat Yield

Figure 4.13, 4.14, and 4.15 show graphs comparing maximum temperature and spring wheat yield for Bottineau, Stutsman, and Morton counties, respectively. Figure 4.13 shows a graph comparing average maximum temperature and spring wheat yield for Bottineau County. In 1988, the average maximum temperature was 84.4ºF and the spring wheat yield was 16.5 bu/acre. In 1990, the average maximum temperature was 79.4ºF and the spring wheat yield was 38 bu/acre In 1993, the average maximum temperature was 72ºF and the spring wheat yield was 36.6 bu/acre as seen below.

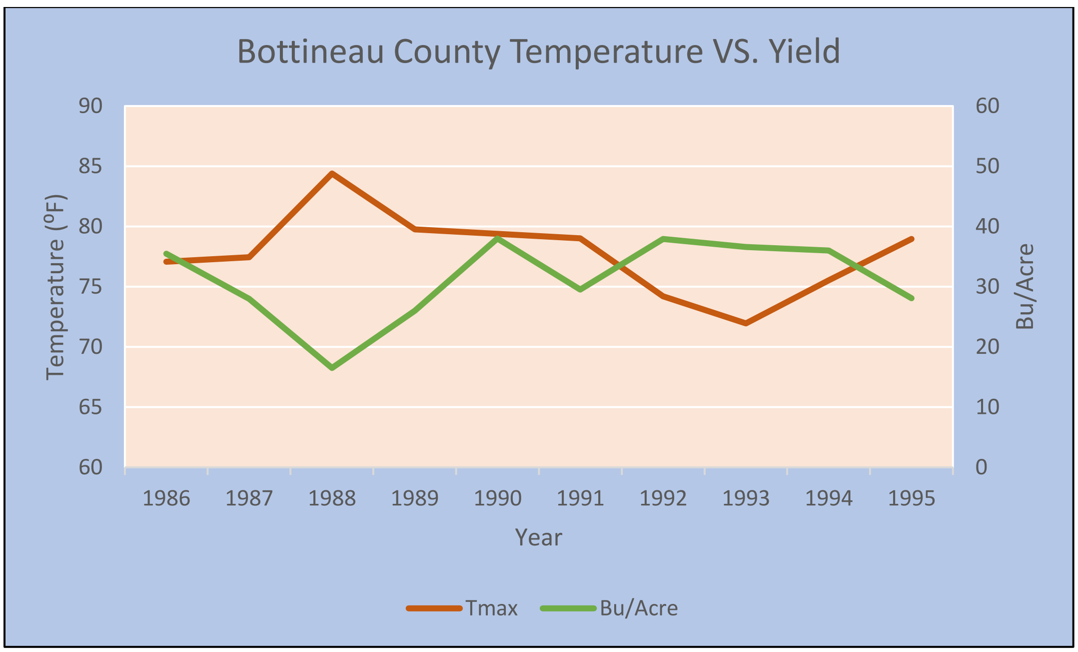

Figure 4.13 Graph Comparing Maximum Temperature and Spring Wheat Yield for Bottineau County. Sources: NOAA and USDA.

Figure 4.14 shows a graph comparing average maximum temperature and spring wheat yield for Stutsman County. In 1988, the average maximum temperature was 88 ºF, and the spring wheat yield was 12.7 bu/acre. In 1990, the average maximum temperature was 80.9 ºF, and the spring wheat yield was 42.2 bu/acre. In 1993, the average maximum temperature was 73.4 ºF, and the spring wheat yield was 30.9 bu/acre as seen below.

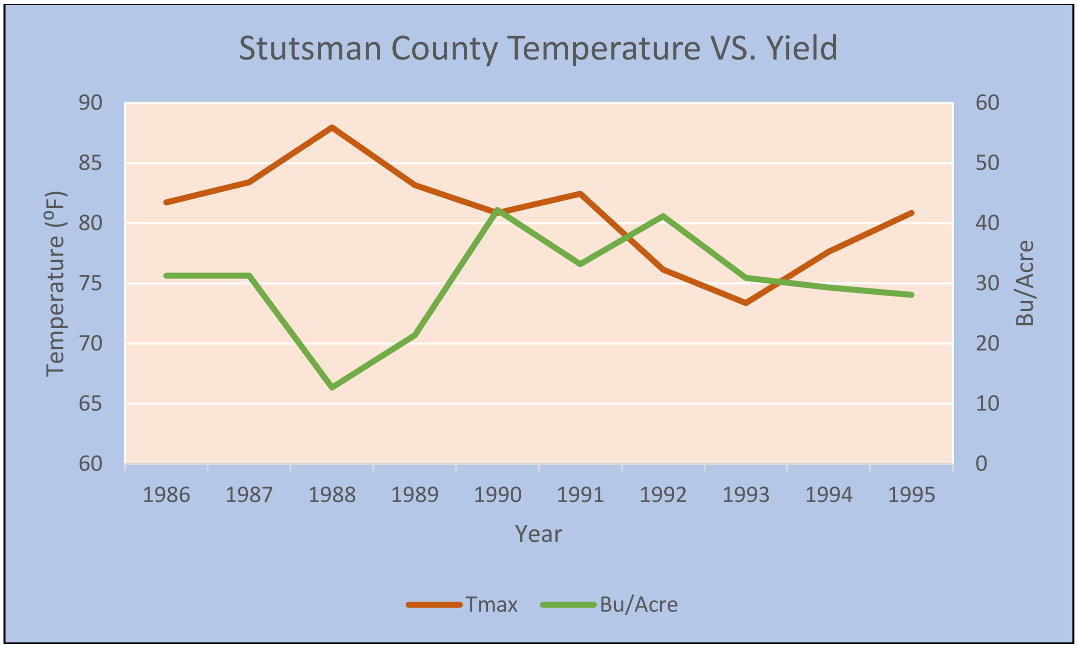

Figure 4.14 Graph Comparing Maximum Temperature and Spring Wheat Yield for Stutsman County. Sources: NOAA and USDA.

Figure 4.15 shows a graph comparing average maximum temperature and spring wheat yield for Morton County. In 1988, the average maximum temperature was 87.5 ºF, and the spring wheat yield was 7.6 bu/acre. In 1990, the average maximum temperature was 83.2 ºF, and the spring wheat yield was 22 bu/acre. In 1993, the average maximum temperature was 74 ºF, and the spring wheat yield was 28 bu/acre as seen below.

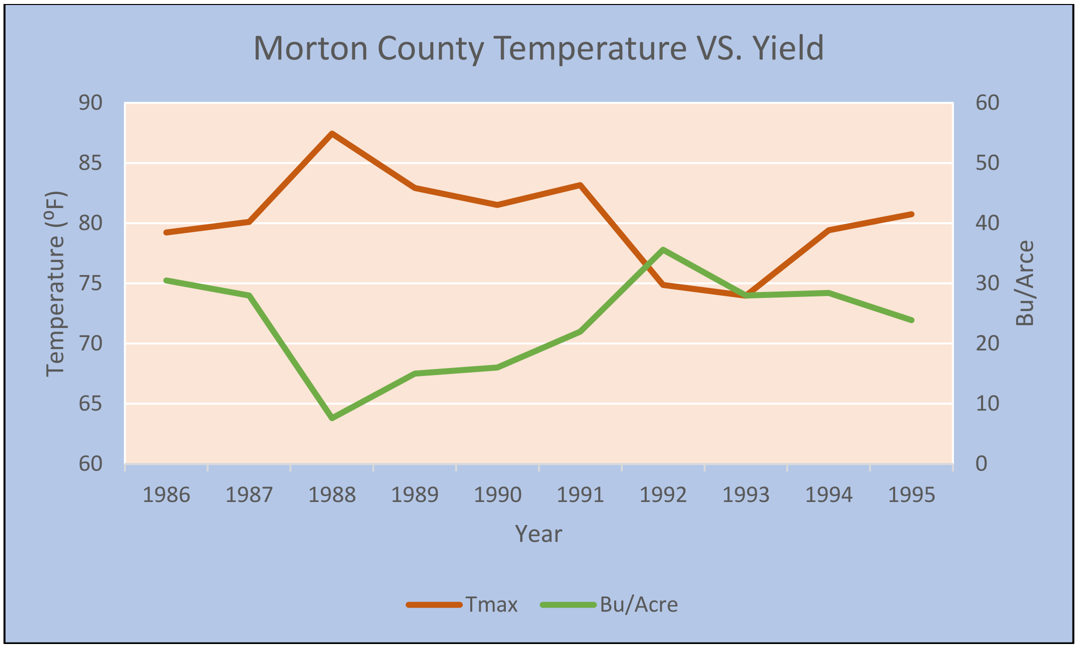

Figure 4.15 Graph Comparing Precipitation and Spring Wheat Yield for Morton County. Sources: NOAA and USDA.

Figure 4.16, 4.17, and 4.18 show graphs comparing precipitation and spring wheat yield for Bottineau, Stutsman, and Morton counties, respectively. Figure 4.16 shows a graph comparing total precipitation and spring wheat yield for Bottineau County. In 1988, the precipitation was 5.09 inches, and the spring wheat yield was 16.6 bu/acre. In 1990, the precipitation was 11.14 inches, and the spring wheat yield was 38 bu/acre. In 1993, the precipitation was 12.6 inches, and the spring wheat yield was 36.6 bu/acre as seen below.

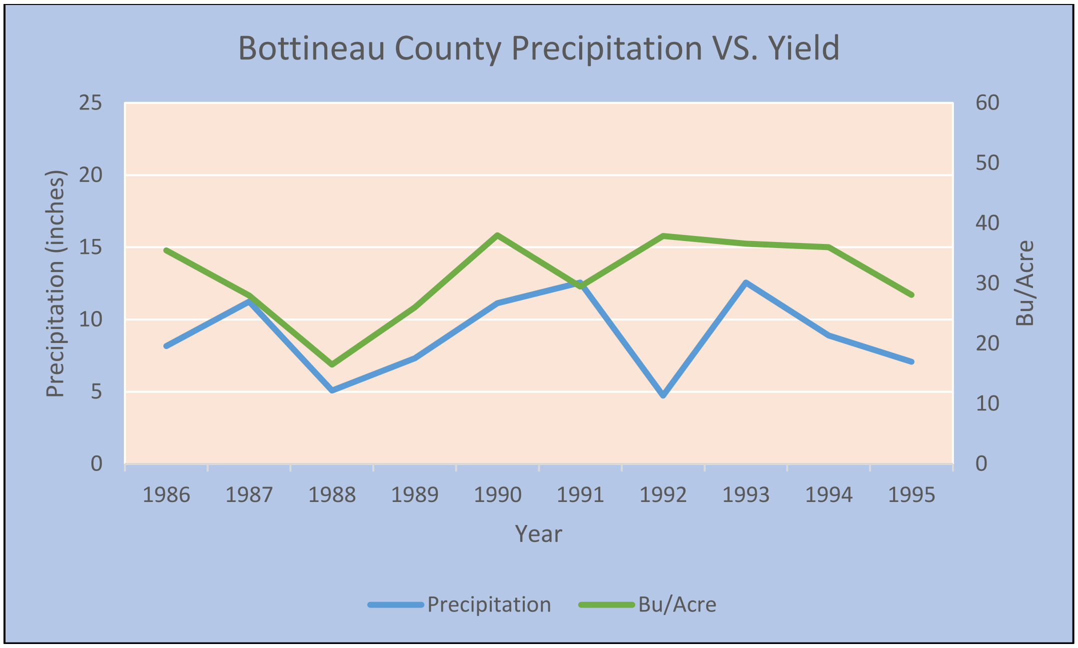

Figure 4.16 Graph Comparing Precipitation and Spring Wheat Yield for Bottineau County. Sources: NOAA and USDA.

Figure 4.17 shows a graph comparing total precipitation and spring wheat yield for Stutsman County. In 1988, the precipitation was 4.8 inches, and the spring wheat yield was 12.7 bu/acre. In 1990, the precipitation was 8.92 inches, and the spring wheat yield was 42.2 bu/acre. In 1993, the precipitation was 20.8 inches, and the spring wheat yield was 30.9 bu/acre, as seen below.

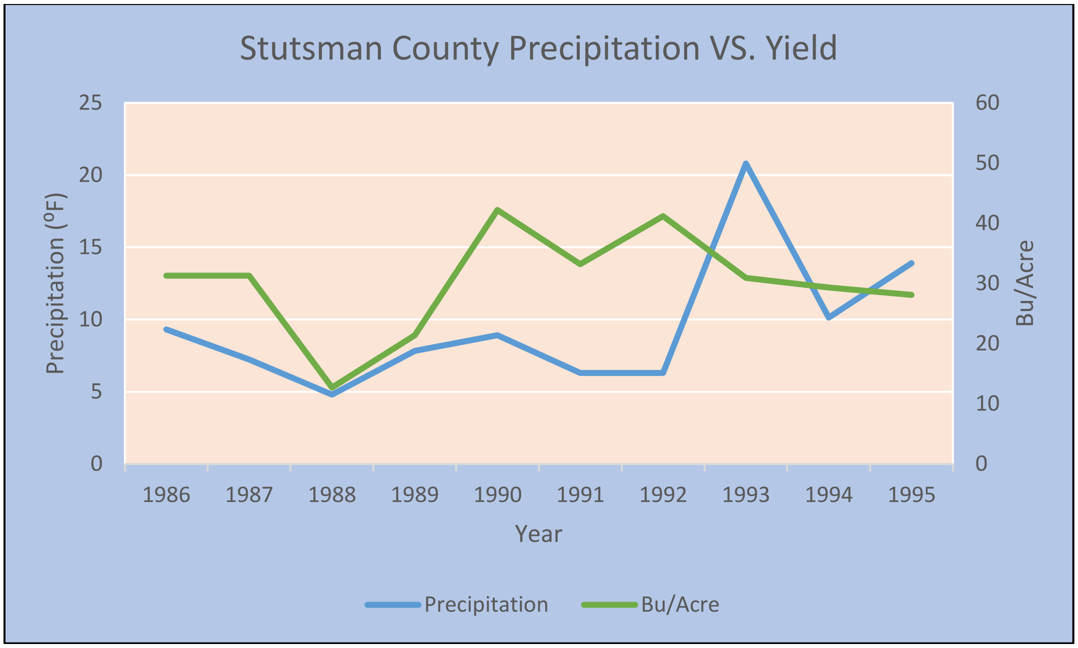

Figure 4.17 Graph Comparing Precipitation and Spring Wheat Yield for Stutsman County. Sources: NOAA and USDA.

Figure 4.18 shows a graph comparing total precipitation and spring wheat yield for Morton County. In 1988, the precipitation was 5.66 inches, and the spring wheat yield was 7.6 bu/acre. In 1990, the precipitation was 8.15 inches, and the spring wheat yield was 16 bu/acre. In 1993, the precipitation was 19.79 inches, and the spring wheat yield was 28 bu/acre, as seen below.

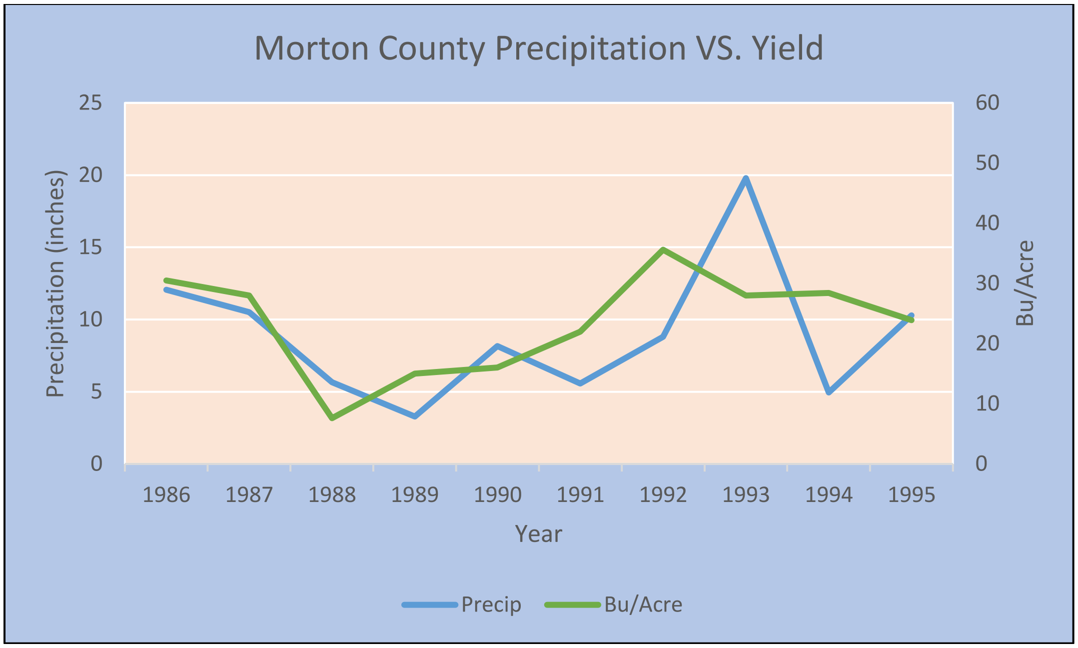

Figure 4.18 Graph Comparing Precipitation and Spring Wheat Yield for Morton County. Sources: NOAA and USDA.

4.3 Western North Dakota: Williams County (Wildrose), McKenzie County (Keene 3 S), and Golden Valley County (Trotters)

4.3.1 Temperature

Table 4.23 shows Western North Dakota's descriptive statistics for maximum temperatures for the 1st period and the 2nd period. The descriptive statistics consisted of minimum temperature, maximum temperature, range, mean, median, mode, variance, and standard deviation for three weather stations: Wildrose, Keene 3 S, and Trotters. The maximum temperatures recorded for Wildrose were 104 ºF, Keene 3 S 106 ºF, Trotters 109 ºF in the 1st period, and 98 ºF, 101 ºF, 104 ºF, respectively, in the 2nd period. In the 1st period, the means calculated for Wildrose were 80 ºF, Keene 3 S 84.16 ºF, and Trotters 83.57 ºF, and 76.65 ºF, 79.13 ºF, and 79.08 ºF, respectively, in the 2nd period. The standard deviations calculated for Wildrose were 9.77, Keene 3 S 9.16, and Trotters 9.72 for the 1st period. The standard deviation calculated for Wildrose were 9.48, Keene 3 S 9.30, and Trotters 9.78 for the 2nd period, as seen below.

Western North Dakota	Temperature Maximum (°F)								Temperature Maximum (°F)							
	1st Period: 1986-1990								2st Period: 1991-1995							
Weather Stations	Min	Max	Rang	Mean	Medi	Mode	Vari	Std.D	Min	Max	Rang	Mean	Medi	Mode	Vari	Std.D
Wildrose	52	104	52	80	80	78	95.49	9.77	45	98	53	76.65	77	79	89.85	9.48
Keene 3 S	55	106	51	84.16	85	89	83.85	9.16	46	101	55	79.13	79	80	86.44	9.3
Trotters	55	109	54	83.57	83	82	94.44	9.72	50	104	54	79.08	79	81	95.56	9.78

Table 4.23 Descriptive Statistics for Western North Dakota of Maximum Temperature for 1st and 2nd periods. Source: NOAA.

Tables 4.24, 4.25, and 4.26 show the difference of means of maximum temperatures for Wildrose, Keene 3 S, and Trotters correspondingly for 1986-1990 and 1991-1995. Table 4.24 shows the difference of means of maximum temperatures for Wildrose for the years 1986-1990 and 1991-1995. The test statistic (calculated) was 5.28. The test statistic value was greater than 1.96, so the null hypothesis was rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table below, 5.28 > 1.96.

Williams (Wildrose)	*Tmax 1st period*	*Tmax 2nd period*
Mean	80.00	76.65
Variance	95.49	89.85
Observations	460.00	460.00
Pearson Correlation	0.00	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	5.28	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.24 Maximum Temperature for Wildrose Difference of Means.
Source: NOAA

Table 4.25 shows the difference of means of maximum temperatures for Keene 3 S for the years 1986-1990 and 1991-1995. The test statistic (calculated) was 8.23. The test statistic value was greater than 1.96, so the null hypothesis was rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table below, 8.23 > 1.96.

McKenzie (Keene 3 S)	*Tmax 1st period*	*Tmax 2nd period*
Mean	84.16	79.13
Variance	83.85	86.44
Observations	460.00	460.00
Pearson Correlation	-0.01	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	8.23	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.25 Maximum Temperature for Keene 3 S Difference of Means. Source: NOAA.

Table 4.26 shows the difference of means of maximum temperatures for Trotters for the years 1986-1990 and 1991-1995. The test statistic (calculated) was 6.92. The test statistic value was greater than 1.96, so the null hypothesis was rejected. The test statistic indicated a significant difference in maximum temperature between the time periods, 1986-1990 and 1991-1995, as seen in the table below, 6.92 > 1.96.

Golden Valley (Trotters)	*Tmax 1st period*	*Tmax 2nd period*
Mean	83.57	79.08
Variance	94.44	95.56
Observations	460.00	460.00
Pearson Correlation	-0.01	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	6.92	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.96	

Table 4.26 Maximum Temperature for Trotters Difference of Means. Source: NOAA.

Table 4.27 shows Wildrose maximum temperature of CV in the 1st period was 12.22% and in the 2nd period was 12.37%. The CV of precipitation for 1st period was 283.51% and in the 2nd period was 270.10%, as seen below.

Wildrose Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	80.00	0.06	Mean	76.65	0.08
S.D	9.77	0.17	S.D	9.48	0.23
Variance	95.49	0.03	Variance	89.85	0.05
CV (%)	12.22	283.51	CV (%)	12.37	270.10
CV	0.12	2.84	CV	0.12	2.70

Table 4.27 Coefficient of Variation: Wildrose, Maximum Temperature and Precipitation. Source: NOAA.

Table 4.28 shows Keene 3 S maximum temperature of CV in the 1st period was 10.88% and in the 2nd period was 11.75%. The CV of precipitation for the 1st period was 357.28% and in the 2nd period was 260.66%, as seen below.

Keene 3 S Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	84.16	0.07	Mean	79.13	0.11
S.D	9.16	0.25	S.D	9.30	0.28
Variance	83.85	0.06	Variance	86.44	0.08
CV (%)	10.88	357.28	CV (%)	11.75	260.66
CV	0.11	3.57	CV	0.12	2.61

Table 4.28 Coefficient of Variation: Keene 3 S, Maximum Temperature and Precipitation. Source: NOAA.

Table 4.29 shows Trotters maximum temperature of CV in the 1st period was 11.63% and in the 2nd period was 12.36%. The CV of precipitation for the 1st period was 372.08% and in the 2nd period was 283.76%, as seen below.

Trotters Coefficient of Variation					
1986-1990			1991-1995		
	Tmax	Precipitation		Tmax	Precipitation
Mean	83.57	0.06	Mean	79.08	0.09
S.D	9.72	0.21	S.D	9.78	0.27
Variance	94.44	0.05	Variance	95.56	0.07
CV (%)	11.63	372.08	CV (%)	12.36	283.76
CV	0.12	3.72	CV	0.12	2.84

Table 4.29 Coefficient of Variation: Trotters, Maximum Temperature and Precipitation. Source: NOAA.

Figure 4.19 shows a climograph with a ten-year span of temperature and precipitation trends for Wildrose. In 1988, the highest average maximum temperature recorded was 84.5ºF. In 1992, the lowest average minimum temperature recorded was 47.9ºF. In 1993, during the months of June, July and August, the highest precipitation received was 13.66 inches and in 1989 the lowest precipitation received was 3.17 inches, as seen below.

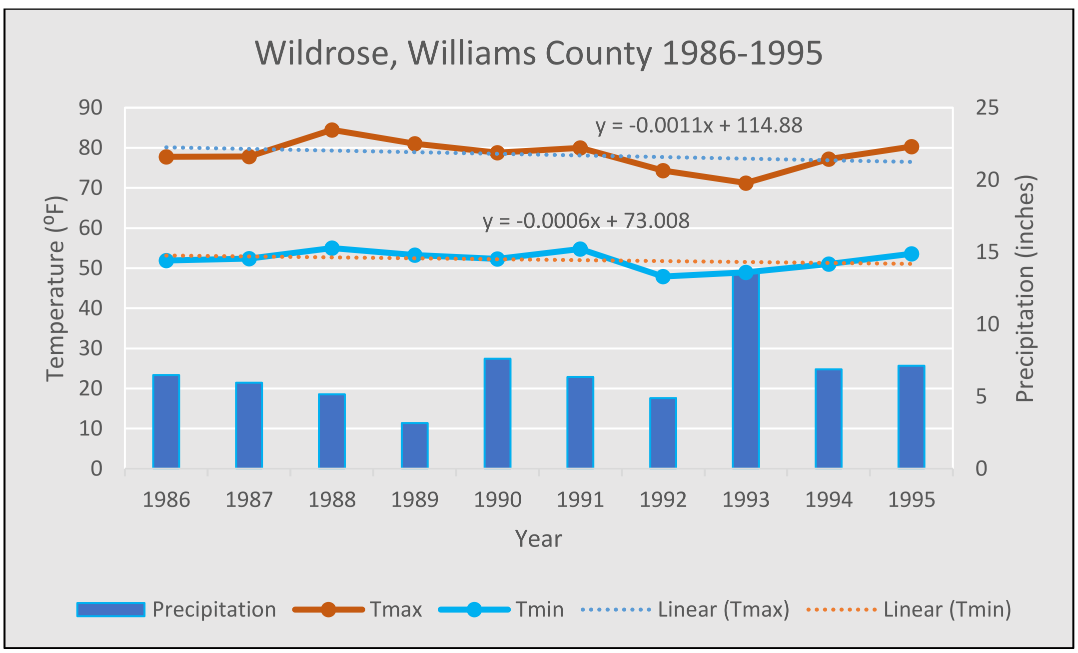

Figure 4.19 Climograph of Temperature and Precipitation Trends for Wildrose. Source: NOAA.

Figure 4.20 shows a climograph with a ten-year span of temperature and precipitation trends for Keene 3 S. In 1988, the highest average maximum temperature recorded was 89.36ºF. In 1992, the lowest average minimum temperature recorded was 49.17ºF. In 1993, during the months of June, July and August, the highest precipitation received was 14.78 inches and in 1988 the lowest precipitation received was 3.78 inches, as seen below.

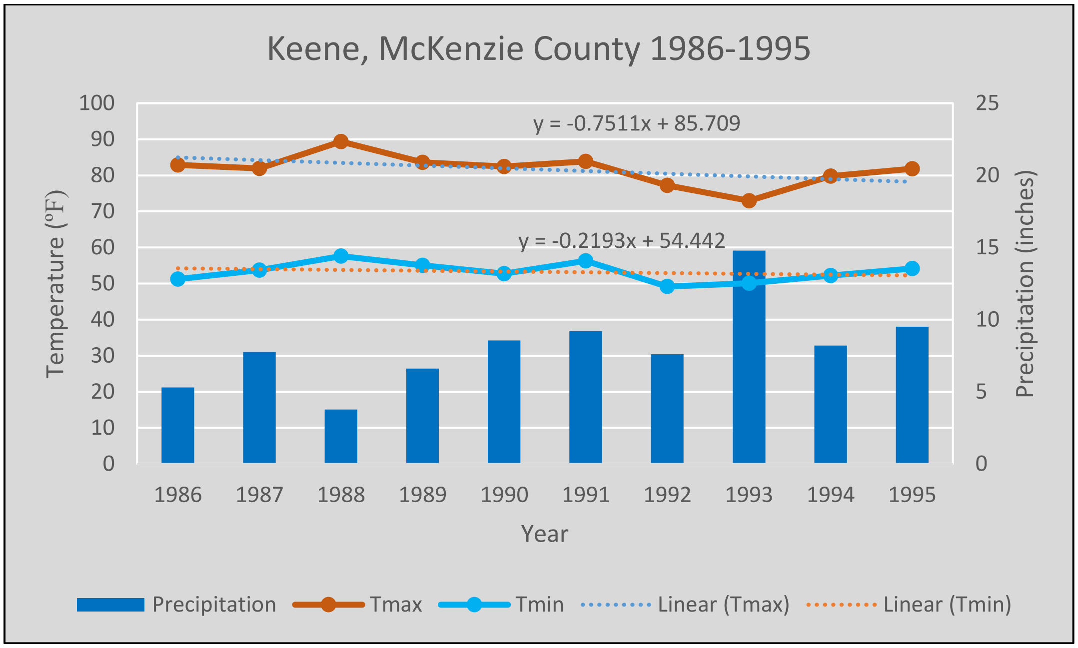

Figure 4.20 Climograph of Temperature and Precipitation Trends for Keene 3 S.
Source: NOAA.

Figure 4.21 shows a climograph with a ten-year span of temperature and precipitation trends for Trotters. In 1988, the highest average maximum temperature recorded was 89.7ºF. In 1992, the lowest average minimum temperature recorded was 49.8ºF. In 1993, during the months of June, July and August the highest precipitation received was 14.48 inches. In 1988, the lowest st

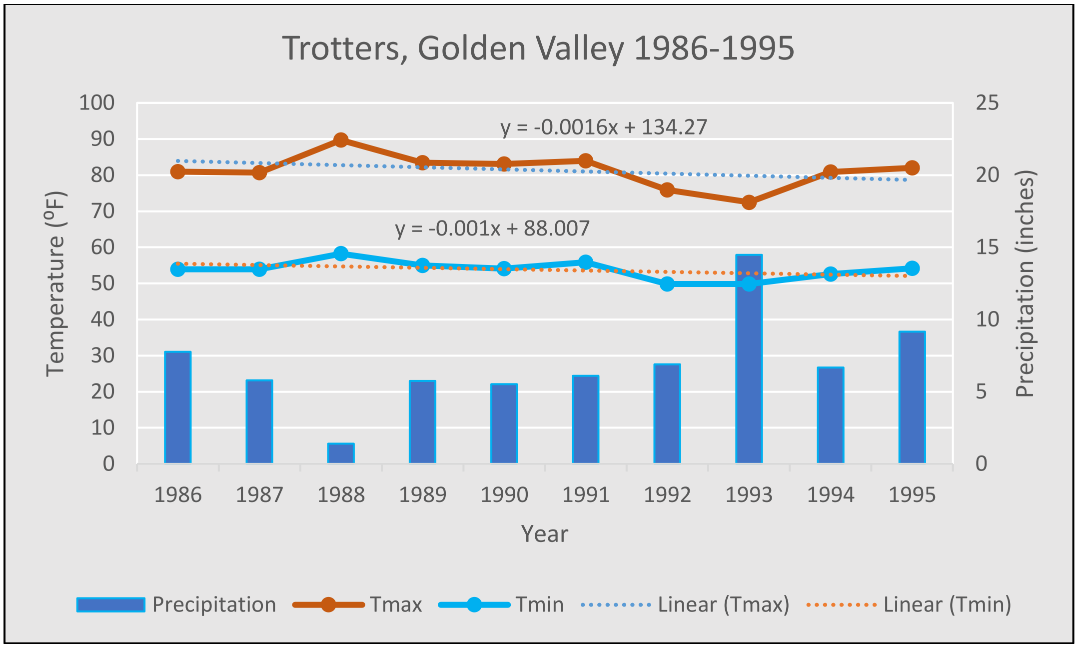

Figure 4.21 Climograph of Temperatures and Precipitation Trends for Trotters. Source: NOAA.

4.3.2 Precipitation

Table 4.30 shows Western North Dakota's descriptive statistics of precipitation for the 1st period and the 2nd period. The descriptive statistics included maximum precipitation, sum, variance, and standard deviation for three weather stations: Wildrose, Keene 3 S, and Trotters. The maximum precipitation recorded for Wildrose were 1.67 inches, Keene 3 S 3.10 inches, Trotters 2.51 inches in the 1st period. The maximum precipitation recorded for Wildrose was 1.76 inches, Keene 3 S 2.57 inches, Trotters 2.94 inches in the 2st period. In the 1st period, the sums calculated for Wildrose were 28.38 inches, Keene 3 S 31.99 inches, and Trotters 26.24 inches. In the 2nd period, the sums calculated were Wildrose 38.91 inches, Keene 3 S 49.31 inches, and 43.90 inches, respectively. The standard deviations calculated were Wildrose 0.17, Keene 3 S 0.25, and Trotters 0.21 for the 1st period. The standard deviations calculated were Wildrose 0.23, Keene 3 S 0.28, and Trotters 0.27 for the 2st period, as seen below.

Western North Dakota	Precipitation (Inches)								Precipitation (inches)							
	1st Period: 1986-1990								2nd Period: 1991-1995							
Weather Stations	Min	Max	Rang	Mean	Sum	Mode	Vari	Std.D	Min	Max	Rang	Mean	Sum	Mode	Vari	Std.D
Wildrose	0	1.67	1.67	0.06	28.38	0	0.03	0.17	0	1.76	1.76	0.08	38.91	0	0.05	0.23
Keene 3 S	0	3.1	3.1	0.07	31.99	0	0.06	0.25	0	2.57	2.57	0.11	49.31	0	0.08	0.28
Trotters	0	2.51	2.51	0.06	26.24	0	0.05	0.21	0	2.94	2.94	0.09	43.3	0	0.07	0.27

Table 4.30 Descriptive Statistics for Western North Dakota of Precipitation for 1st and 2nd Periods. Source: NOAA.

Table 4.31 shows the difference of means in precipitation for Wildrose during the years 1986-1990 and 1991-1995. The test statistic (calculated) was -1.70. The Wildrose weather station's test statistic value was greater than -1.96, so the null hypothesis was not rejected. As seen in the table below, -1.70 > -1.96. This means there is not a significant difference in precipitation between the two periods in the study.

Williams (Wildrose)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.06	0.08
Variance	0.03	0.05
Observations	460.00	460.00
Pearson Correlation	0.00	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-1.70	
P(T<=t) one-tail	0.04	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.09	
t Critical two-tail	1.96	

Table 4.31 Precipitation for Wildrose Difference of Means. Source: NOAA.

Table 4.32 shows the difference of means in precipitation for Keene 3 S during the years 1986-1990 and 1991-1995. The test statistic (calculated) was -2.13. The Keene 3 S weather station's test statistic value was less than -1.96, so the null hypothesis was rejected, as seen in the table below, -2.13 < -1.96 . This means there is a significant difference in precipitation between the two periods in the study.

McKenzie (Keene 3 S)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.07	0.11
Variance	0.06	0.08
Observations	460.00	460.00
Pearson Correlation	-0.03	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-2.13	
P(T<=t) one-tail	0.02	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.03	
t Critical two-tail	1.96	

Table 4.32 Precipitation for Keene 3 S Difference of Means. Source: NOAA.

Table 4.33 shows the difference of means in precipitation for Trotters during the years 1986-1990 and 1991-1995. The test statistic (calculated) was -2.29. The Trotters weather station's test statistic value was less than -1.96, so the null hypothesis was rejected, as seen in the table, -2.29 < -1.96. This means there is a significant difference in precipitation between the two periods in the study.

Golden Valley (Trotters)	*Precipitation 1st*	*Precipitation 2nd*
Mean	0.06	0.09
Variance	0.05	0.07
Observations	460.00	460.00
Pearson Correlation	-0.04	
Hypothesized Mean Difference	0.00	
df	459.00	
t Stat	-2.29	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.02	
t Critical two-tail	1.96	

Table 4.33 Precipitation for Trotters Difference of Means. Source: NOAA.

4.3.3 Spring Wheat Yield

Figure 4.22 shows a graph comparing average maximum temperature and spring wheat yield for Williams County. In 1988, the average maximum temperature was 84.5 ºF, and the spring wheat yield was 7.5 bu/acre. In 1990, the average maximum temperature was 78.8 ºF, and the spring wheat yield was 21.5 bu/acre. In 1993, the average maximum temperature was 71.2 ºF, and the spring wheat yield was 37.3 bu/acre, as seen below.

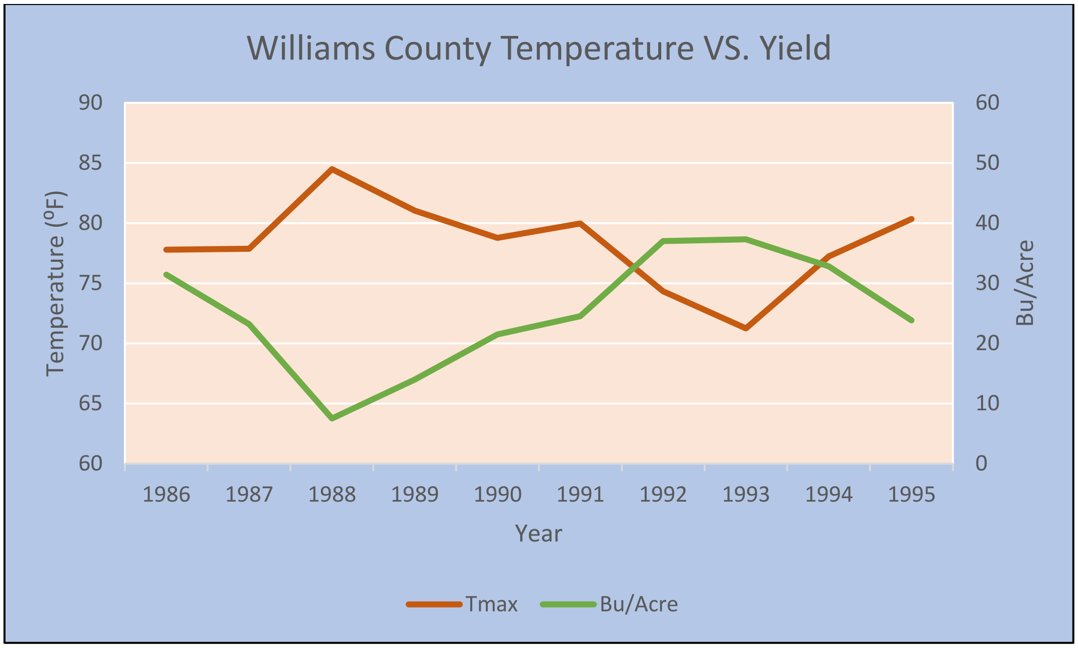

Figure 4.22 Graph Comparing Maximum Temperature and Spring Wheat Yield for Williams County. Sources: NOAA and USDA.

Figure 4.23 shows a graph comparing average maximum temperature and spring wheat yield for McKenzie County. In 1988, the average maximum temperature was 89.36 ºF, and the spring wheat yield was 9 bu/acre. In 1990, the average maximum temperature was 82.41 ºF, and the spring wheat yield was 30 bu/acre. In 1993, the average maximum temperature was 72.97 ºF, and the spring wheat yield was 36.6 bu/acre, as seen below.

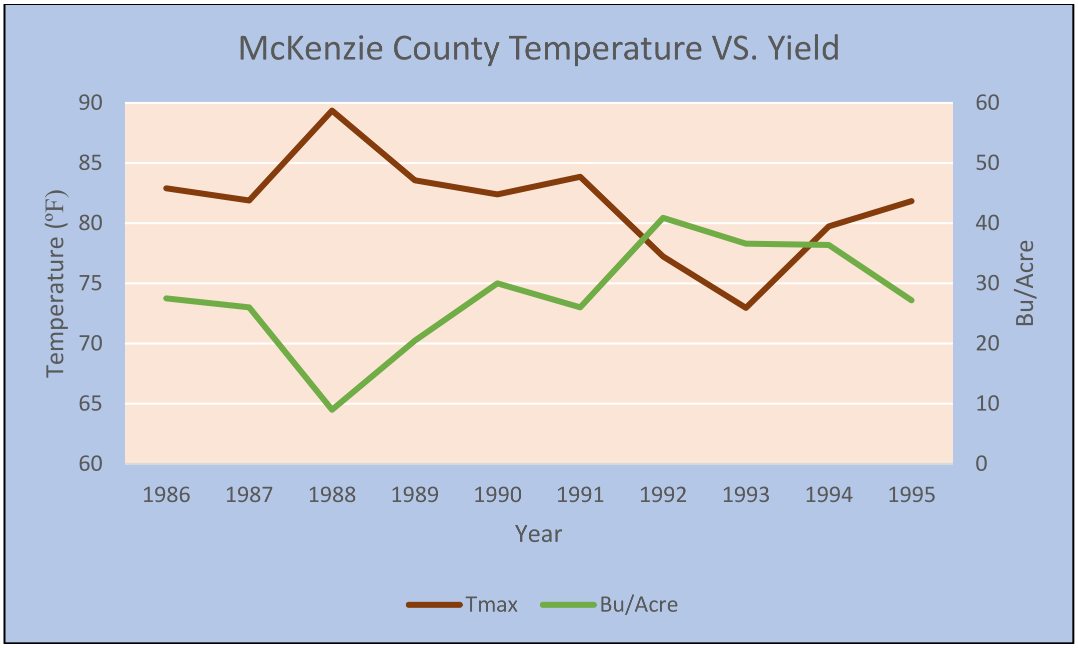

Figure 4.23 Graph Comparing Maximum Temperature and Spring Wheat Yield for McKenzie County. Sources: NOAA and USDA.

Figure 4.24 shows a graph comparing average maximum temperature and spring wheat yield for Golden Valley County. In 1988, the average maximum temperature was 89.7 ºF, and the spring wheat yield was 6 bu/acre. In 1990, the average maximum temperature was 83.1 ºF, and the spring wheat yield was 24.5 bu/acre. In 1993, the average maximum temperature was 72.5 ºF, and the spring wheat yield was 33.9 bu/acre, as seen below.

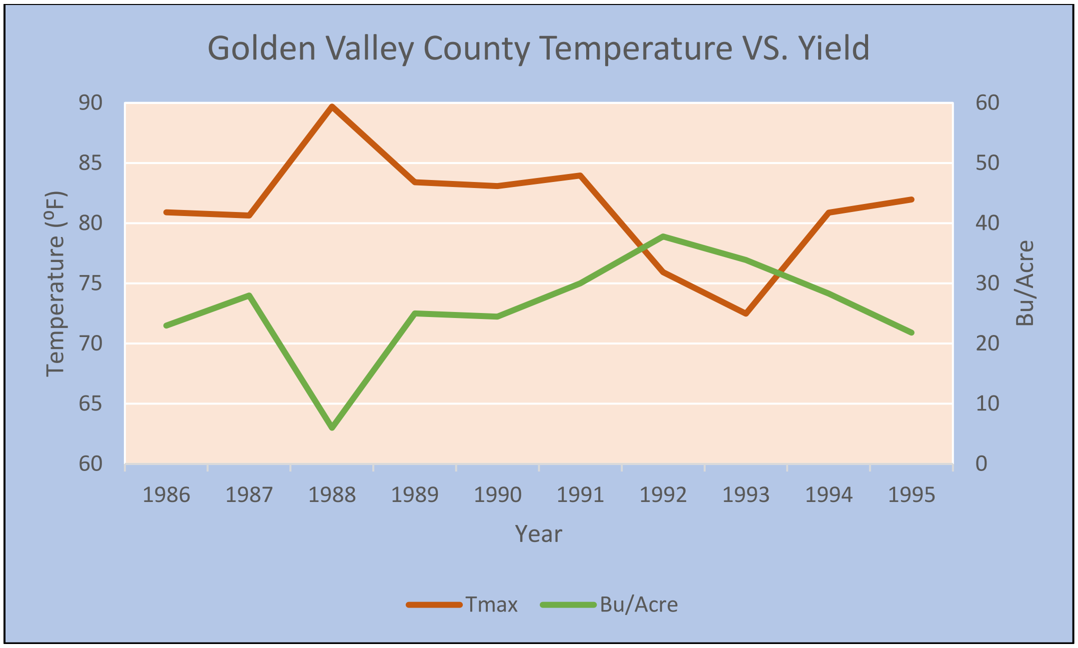

Figure 4.24 Graph Comparing Maximum Temperature and Spring Wheat Yield for Golden Valley County. Sources: NOAA and USDA.

Figure 4.25 shows a graph comparing total precipitation and spring wheat yield for Williams County. In 1988, the precipitation was 5.15 inches, and the spring wheat yield was 7.5 bu/acre. In 1990, the precipitation was 7.62 inches, and the spring wheat yield was 21.5 bu/acre. In 1993, the precipitation was 13.66 inches, and the spring wheat yield was 37.3 bu/acre, as seen below.

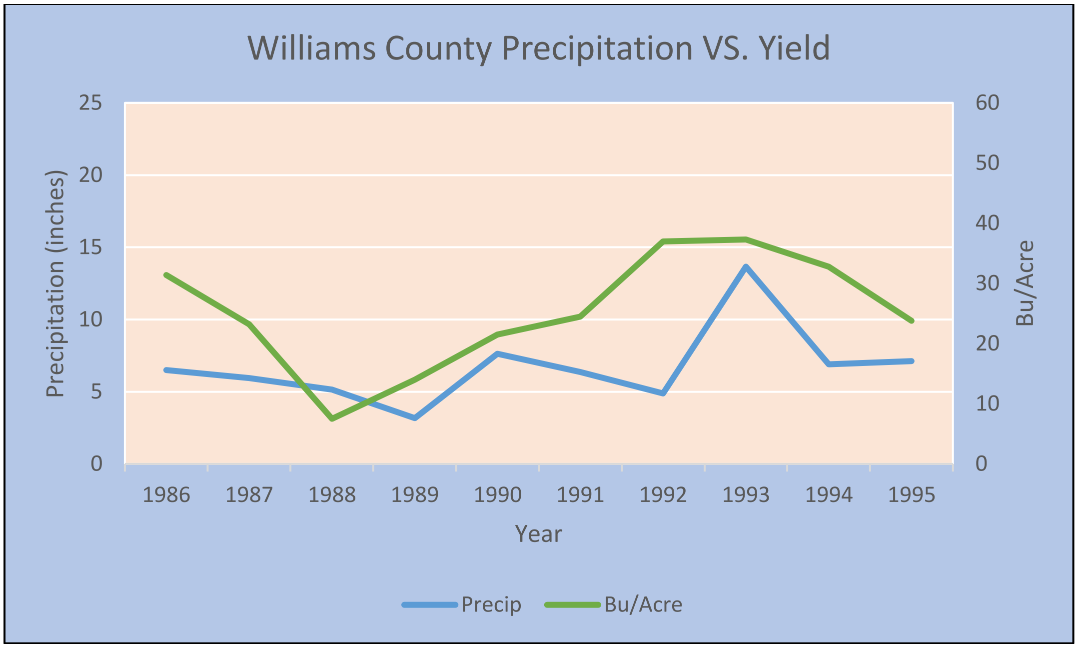

Figure 4.25 Graph Comparing Precipitation and Spring Wheat Yield for Williams County. Sources: NOAA and USDA.

Figure 4.26 shows a graph comparing total precipitation and spring wheat yield for McKenzie County. In 1988, the precipitation was 3.78 inches, and the spring wheat yield was 9 bu/acre. In 1990, the precipitation was 8.55 inches, and the spring wheat yield was 30 bu/acre. In 1993, the precipitation was 14.78 inches, and the spring wheat yield was 36.6 bu/acre, as seen below.

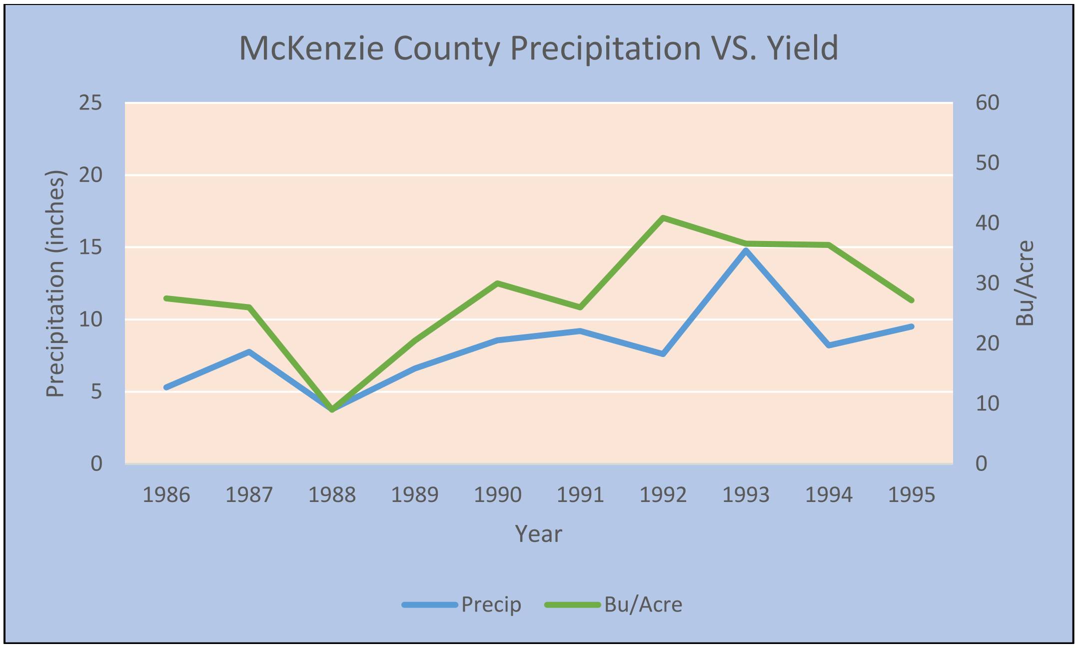

Figure 4.26 Graph Comparing Precipitation and Spring Wheat Yield for McKenzie County. Sources: NOAA and USDA.

Figure 4.27 shows a graph comparing total precipitation and spring wheat yield for Golden Valley County. In 1988, the precipitation was 1.41 inches, and the spring wheat yield was 6 bu/acre. In 1990, the precipitation was 5.52 inches, and the spring wheat yield was 24.5 bu/acre. In 1993, the precipitation was 14.48 inches, and the spring wheat yield was 33.9 bu/acre, as seen below.

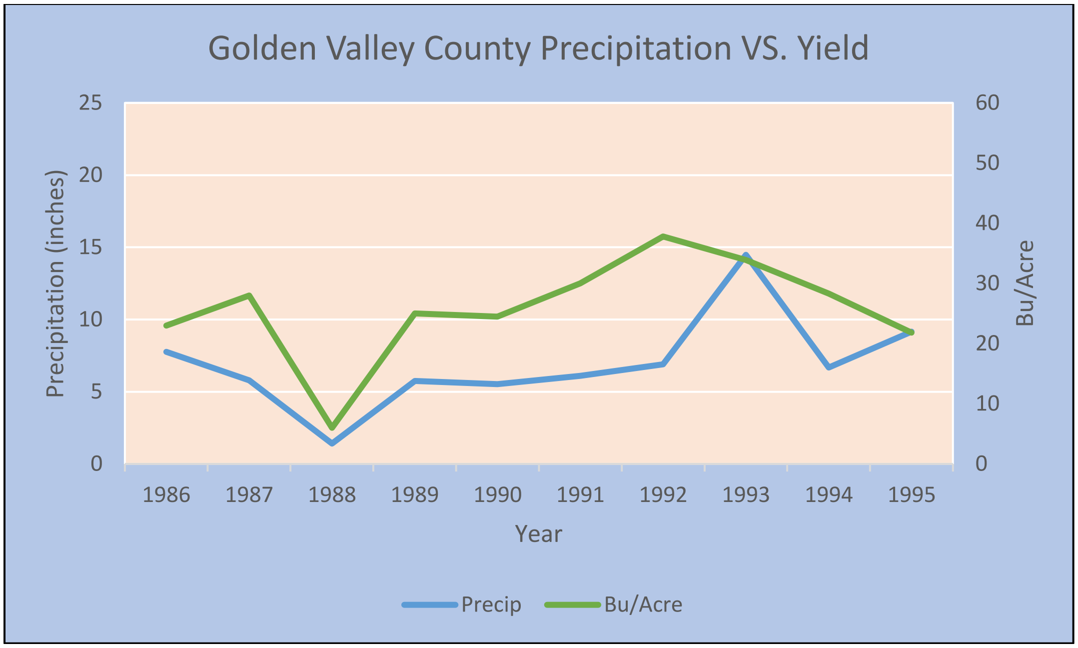

Figure 4.27 Graph Comparing Precipitation and Spring Wheat Yield for Golden Valley County. Sources: NOAA and USDA.

4.4 Overall Results

The maximum temperatures for eastern, central, and western North Dakota's weather stations' the test statistic values are higher than 1.96, so the null hypothesis are rejected. This means there are significant differences in maximum temperatures between the two periods in the study.

In contrary, for eastern North Dakota's weather station, Fargo, the test statistic value was lower than -1.96, so the null hypothesis was not rejected. There is not a significant difference in precipitation. However, for Grand Forks and Ashley, the test statistic values were higher than 1.96 or -1.96, so the null hypothesis were rejected. This means there are significant differences in precipitation between the periods for these two weather stations. For central North Dakota's weather stations, Bottineau, Jamestown, and Mandan, the test statistic values were lower than -1.96, so the null hypothesis were not rejected. There is not a significant difference in precipitation between the periods for these three weather stations. For western North Dakota's weather stations, Wildrose, the test statistic values were lower than -1.96, so the null hypothesis were not rejected. There is not a significant difference in precipitation between the periods for these three weather stations. However, the weather stations Keene 3 S and Trotters, the test statistic values are higher than -1.96, so the null hypothesis was rejected. This means there are significant differences in precipitation between the periods for these two weather stations. Having presented the results in this chapter, the research discussion is addressed in Chapter 5.

CHAPTER 5

DISCUSSION

The IPCC (2013) reported that the greatest change in temperature for the Northern Great Plains was 1.06°C and a decadal increase of 0.238°C over the previous sixty years. Similarly, the global average temperature also increased during this time (IPCC 2013). Throughout the northern Great Plains, the winter months have been warming compared to the summer months. A study was done by Folland, et al. (1990) found that winter temperatures increased more than summer temperatures. This increase in winter temperatures may be attributable to the increased cloud cover mentioned by Karl (1993), and this could be because of the amount of snow and vegetation cover during the winter season. Drought is caused by long time variability of both precipitation and evaporation and extreme precipitation is expected to increase with warming (IPCC 2013). Both the increase in temperatures and extreme precipitation may lead to the northern Great Plains drought or wet conditions that could interfere with spring wheat yield in North Dakota.

An understanding of how plants respond to environmental stresses at different growth stages can assist in the assessment of crop condition and production potential throughout the growing season (Wiersma and Ransom 2005). To understand crop yield, it is important to recognize critical growth stages of plants and how heat and water stress affect plant development. The optimum temperature for spring wheat growth is about 75 ºF-77 ºF (25 ºC). For minimum growth temperatures of 37.4 ºF (3 ºC) to 39.2 ºF (4 ºC) are needed; for maximum growth temperatures of 86 ºF (30 ºC) to 89.6 ºF (32 ºC) are required (Briggle 1980; Wiersma and Ransom 2005). The average number of days each growing season that exceed 90 ºF is probably a rough indicator of temperature stress (Campbell 1987; Wiersma and Ransom 2005). The primary driving force that advances plant development and determines the development rate is heat or thermal energy. The range of plant-development rate depends on a minimum survival temperature to an optimum temperature. However, the plant-development rate may remain the same when at the optimum temperature; if temperatures are greater than optimum, the plant development may decline (Bauer, et al. 1992). Ideal annual precipitation ranges are from 14.7 inches (375 mm) to 34.4 inches (875mm) for wheat growth (Leonard and Martin 1963).

Average spring wheat yield in North Dakota is about 46 (bu/acre) in a normal year (USDA 2016), but yield may fluctuate from changes in temperature, precipitation, soil moisture, planting time, crop rotation, seed quality, and environment. Critical growth periods of germination, tillering (appearance of leaves on the main shoot), and head emergence with flowering are directly influenced by temperature and precipitation. The germination or early-stage process begins with minimal water, but drought stress can reduce the number of tillers and root mass. The main crown root system, the floral structures and kernels are being formed during tillering time. The main crown root system delivers optimal plant nutrients and water during the growing season. Drought and heat stress should be minimized, while cool weather during the early phase of development favors uniform tillering and large spikes. During head emergence and the flowering period, the wheat plant is sensitive to both high temperature and freezing conditions which can cause floret abortion and reduction in grain weight (Wiersma and Ransom 2005; Fowler 2019).

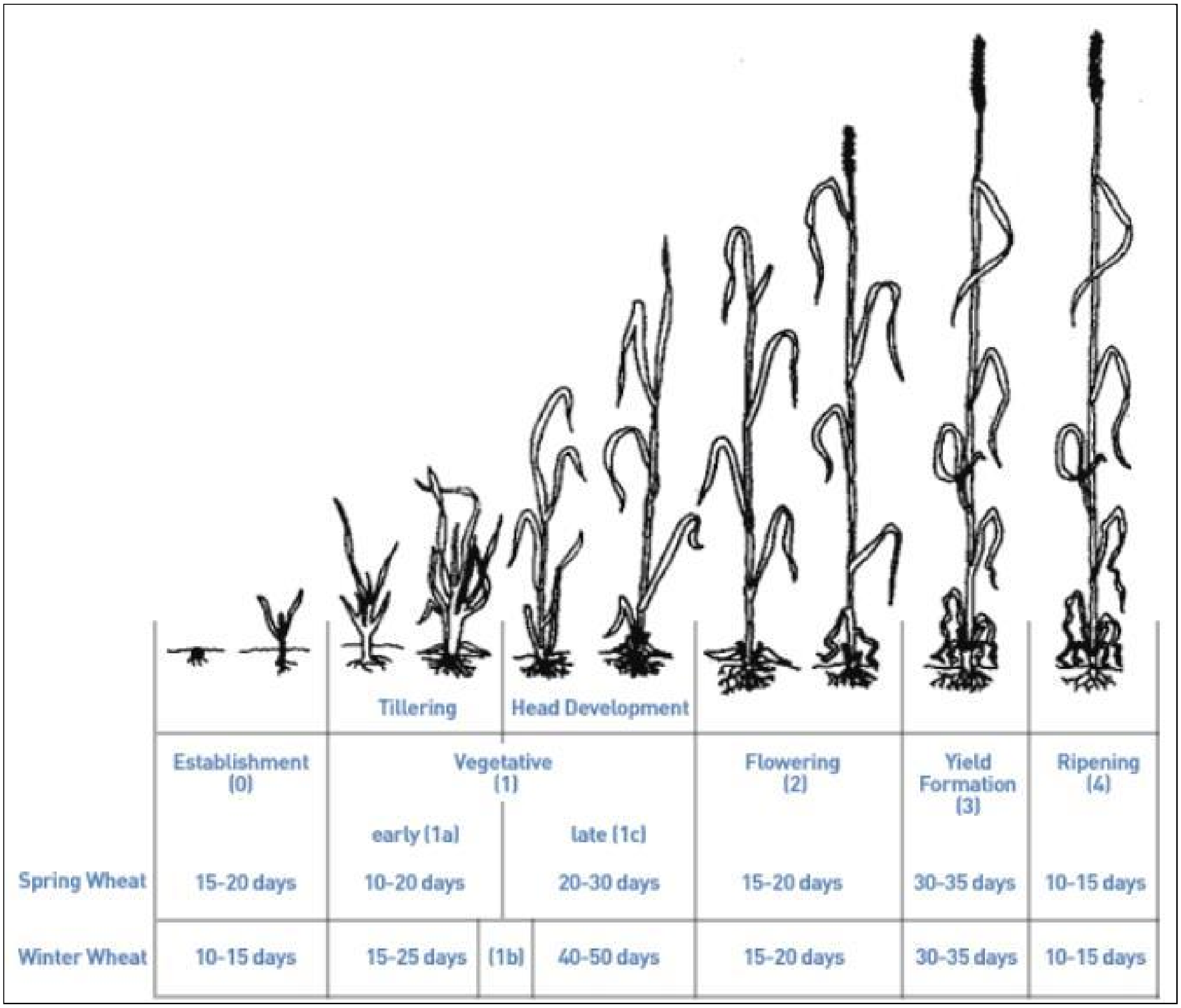

Figure 5.1 Shows Different Stages of Spring and Winter Wheat Plant Development.
Source: Food and Agriculture Organization of the United Nations.

The average number of days per year with maximum temperatures of 90ºF is 10 days in the northwest and 24 days in the southwest. Temperatures of 100ºF or more occur nearly every year in North Dakota, but they are most prevalent in the drier south-west and south-central areas with about two days per year. Temperatures of 100ºF or more occurs in the wetter east and northeast regions about one day every four or five years (Enz 2003). Average precipitation ranges from 14 to 22 inches from northwestern to southeastern North Dakota and about 70 percent of the annual precipitation falls during the crop-growing season, April to September, with 50-60 percent falling during April through July (Enz 2003; State Historical Society of North Dakota 2019). In the north-east and north-central regions the average growing season is about 110 to 120 days while in the south-west and south-central regions, the average growing season is about 130 days. Further, long hours of summer sunshine makes it possible to grow wheat during a relatively short growing season (Enz 2003). The higher temperatures may increase growth rates and yields in the Red River Valley, but growth can be compromised where moisture is severely limited (Campbell 1987).

Across North Dakota, geological and climatic patterns differ in each physiographic region. North Dakota is subdivided into three main physiographic regions: the Red River Valley, the Drift Prairie, and Missouri Plateau as shown Figure 5.2. These regions' land elevation and dryness increases from east to west. Eastern North Dakota receives more precipitation than western North Dakota. Average July temperatures range from 65ºF in the northeast to 71 ºF- 72 ºF in the south. The Red River Valley is extremely flat and has the lowest land in North Dakota, consisting of rich soil, and elevation ranging between 750 and 950 feet above the sea level, respectively, from south to north. The fertility of the soil of each region is different (Enz 2003; and State Historical Society of North Dakota 2019). The Drift Prairie or Glaciated Plains is the second highest land region consisting of less fertile soil, more rocks, and other material. The elevation here is higher than the Red River Valley. The Missouri Plateau or Missouri Coteau consists of steeply-rolling topography primarily used for rangeland, and the soil of this region is sandy and much less fertile than soils farther east. The different patterns in landscape, climate, and soil fertility play a major role in North Dakota spring wheat production.

Figure 5.2 Three Main Physiographic Regions in North Dakota. Source: Nations Online Project

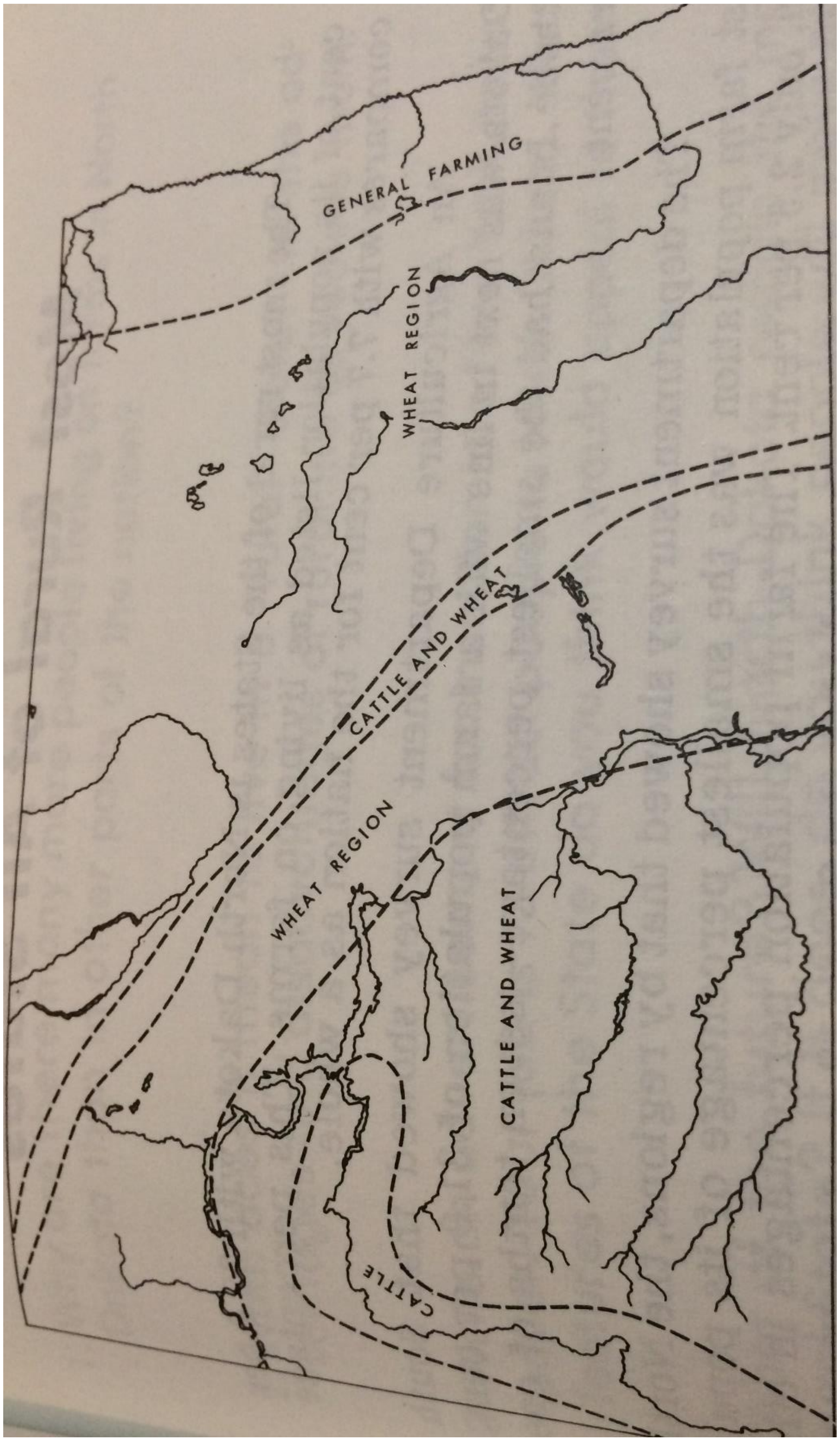

Figure 5.3 Shows North Dakota Wheat-Producing Regions. Source: Richardson, S. 2015.

5.1 Temperature

The optimum temperature for spring wheat growth is about 75 ºF-77 ºF. During the 1st period, all nine weather stations average maximum temperature ranged from 79 ºF to 84 ºF, which shows the1st period's maximum temperature exceeded the optimum temperature for spring wheat growth. In 1988, all nine weather stations experienced heat stress in some degree because the average maximum temperatures were higher than the optimum temperature.

During the 1st period, 1988 was the warmest growing season. The four highest temperature stations were Trotters (89.7 °F), Keene 3 S (89.3 °F), Jamestown (88 °F), and Ashley (87.9 °F). Trotters and Keene 3 S are located in western North Dakota. The Trotters weather station is located in south-western North Dakota in the Missouri Plateau that consists of rolling topography, sand and less-fertile soils, where average July temperature ranges from 71ºF-72 ºF. The optimum temperature for spring wheat growth is about 75 ºF-77 ºF. As mentioned earlier, the average number of days per year with maximum temperatures of 90 ºF is 24 days in southwest North Dakota. Northwest North Dakota sees 10 days of 90 ºF temperatures. However, the average number of days each growing season exceeded 90 ºF in Trotters was 48 days with Keene 3 S registering 50 days that caused extreme drought conditions (see Table 5.1). On the other hand, during the early-tillering phase, plant growth cannot tolerate heat stress. During June 1988, both stations' maximum temperature were more than 20 days causing floret abortion in plants early development. Furthermore, in 1988, eastern North Dakota, central North Dakota, western North Dakota showed similar patterns. In contrary, during the 2nd period, the maximum temperature for all weather stations ranged from 76 ºF to 79 ºF within under the optimum temperature for spring wheat growth.

Counties	Weather Stations	Months	1988				1993			
			Days 90°F	Monthly Tmax	Precipitation (in)	Yield (bu/acre)	Days 90°F	Monthly Tmax	Precipitation (in)	Yield (bu/acre)
Grand Forks	Grand Forks	June	11	85.7	1.34	26.7	1	72.23	4.59	33
		July	9	86.4	3.73		0	74.41	7.49	
		August	4	83	1.34		1	77.77	4.9	
Cass	Fargo	June	13	87.63	1.24	19.1	0	73.5	4.28	32.3
		July	14	90.09	0.46		0	76	7.71	
		August	7	84.87	2.14		5	80.35	1.13	
McIntosh	Ashley	June	17	88.53	1.74	6	0	70.02	8.18	21.3
		July	17	89.67	0.38		0	73.54	7.6	
		August	10	85.45	1.57		1	77.09	4.73	
Bottineau	Bottineau	June	16	88	1.39	16.5	1	70.63	4.15	36.6
		July	8	83.29	2.34		0	70.12	5.27	
		August	6	81.8	1.36		1	75.09	3.14	
Stutsman	Jamestown	June	16	88.63	1.91	12.7	0	70.03	7.42	30.9
		July	18	90.87	1.58		0	72.87	11.06	
		August	9	84.38	1.31		3	77.19	2.32	
Morton	Mandan	June	21	91.1	0.91	7.6	1	71.03	4.48	28
		July	13	87.19	1.52		0	73.35	13.43	
		August	12	84.06	3.23		1	77.54	1.88	
Williams	Wildrose	June	14	88.9	1.93	7.5	1	68.6	3.19	37.3
		July	6	83.29	2.43		0	70.7	8.43	
		August	6	81.25	0.79		0	74.41	2.14	
McKenzie	Keene 3 S	June	22	92.26	2.67	9	2	70.63	4.6	36.6
		July	13	88.35	1.5		0	72.09	8.25	
		August	15	87.54	0.06		0	76.09	1.93	
Golden Velley	Trotters	June	21	92.63	0.98	6	2	70.06	4.75	33.9
		July	15	89.9	0.32		0	71.67	7.51	
		August	12	86.54	0.11		0	75.7	2.22	

Table 5.1 Summer 90 Degree Temperatures Versus Spring Wheat Yield in North Dakota.
Sources: NOAA; NASS.

5.2 Precipitation

The ideal annual precipitation ranges from 14.7 inches (375mm) to 34.4 inches (875mm) for wheat growth. Long-term average precipitation usually received is 22 inches in southeastern North Dakota and 14 inches in northwestern North Dakota. In the 1st period, lowest total precipitation received during June, July, and August included Trotters (26.24 inches), Keene 3 S (26.24 inches), and Wildrose (28.38 inches). Nevertheless, the following four weather stations: Trotters (1.41 inches), Ashley (3.69 inches), Keene 3 S (3.78 inches) and Fargo (3.84 inches) received the lowest precipitation in 1988. Crown formation or main crown root system is a wheat plant growth development with five leaves, two tillers, and a well-developed crown. During the growing season, the crown root system provides plant with most nutrients and water that favors uniform tillering and large spikes (Fowler 2019). Because 1988 received lower than ideal precipitation, some plants died without nutrients and water. In the 2nd period, the total precipitation ranged from 38.9 inches to 61 inches. The most precipitation received during June, July, and August included Grand Forks (61 inches), Jamestown (57.4 inches), Ashley (56.6 inches), and Fargo (52.33 inches). During the 2nd period, 1993 was the wetter season. In 1993, the highest precipitation received was Ashley (20.51 inches), Jamestown (20.8 inches), Mandan (19.79 inches), and Grand Forks (16.98 inches) during the summer months. Even though eastern North Dakota should receive more rain than western North Dakota, it appears 1993 in western North Dakota weather stations precipitation measured close to the optimal precipitation, which favors western North Dakota's spring wheat yield.

Table 1.2. Average water use for wheat in inches/day for North Dakota.

Temperature °F	Week After Emergence 1	2	3	4	5	6	7	8	9	10	11	12	13	14
50-59	.01	.03	.04	.06	.07	.08	.08	.08	.08	.08	.07	.06	.04	.03
60-69	.02	.04	.07	.10	.12	.14	.14	.14	.14	.14	.12	.10	.07	.04
70-79	.03	.06	.10	.13	.17	.19	.19	.19	.19	.19	.17	.14	.10	.06
80-89	.04	.08	.12	.17	.22	.24	.24	.25	.25	.25	.22	.17	.12	.08
90-99	.05	.10	.15	.21	.26	.29	.30	.30	.30	.30	.27	.21	.15	.09
Growth Stages			↑ Tillering		↑ Jointing	↑ Boot	↑ Heading		↑ Early Milk		↑ Early Dough	↑ Hard Dough		

Figure 5.4 Average Water Use for Wheat Growth in North Dakota. Source: Wiersma and Ransom 2005.

5.3 Spring wheat yield

Spring wheat yield in North Dakota depends on climatic and non-climatic factors. Within climatic factors, temperature and precipitation are the most important factors for spring wheat yield. Table 5.2 is showing nine counties average maximum temperatures, total precipitations, and total spring wheat yields for the periods. Within the nine counties, the highest producing yields are Grand Forks, Cass, and Bottineau counties for both the 1st and the 2nd periods. These three counties are located respectively in north-east, east-central, and north-central North Dakota. Table 5.3 shows nine selected counties' two critical years, 1988 and 1993, average HRS spring wheat yield compared with 2018 numbers and the 1919-1983 historic data.

	Regions	Counties	Weather Stations	Tmax (ºF) 1986-1990	Precip (inches) 1986-1990	Total Yield 1986-1990	Tmax (ºF) 1991-1995	Precip (inches) 1991-1995	Total Yield 1991-1995
Eastern ND	**North East**	Grand Forks	Grand Forks	81.3	37.17	194.4	77.91	61.01	193.4
	East Central	Cass	Fargo	82.6	37.09	180.7	78.81	52.33	190.2
	South East	McIntosh	Ashley	82.4	37.83	84.5	77.01	56.64	125.4
Central ND	**North Central**	Bottineau	Bottineau	79.6	42.96	144	75.93	45.82	168.1
	Central	Stutsman	Jamestown	83.4	38.11	138.9	78.10	57.41	162.7
	South Central	Morton	Mandan	82.3	39.64	97.1	78.44	49.4	137.9
Western ND	**North West**	Williams	Wildrose	80.0	28.38	97.6	76.62	38.91	155.4
	West Central	McKenzie	Keene 3 S	83.55	26.24	113	79.13	49.31	167.1
	South West	Golden Valley	Trotters	83.5	26.24	106.5	79.04	43.3	151.8

Table 5.2 Showing Average Maximum Temperature, Total Precipitation, and Total Spring Wheat Yield for Nine Counties for the 1st Period and the 2nd Period. Sources: NOAA and NASS

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County	1919-1983 Average Yield (bu/acre)	1988 Average Yield (bu/acre)	1993 Average Yield (bu/acre)	2018 Average Yield (bu/acre)
Grand Forks	21.7	26.7	33.0	58.5
Cass	20.6	19.1	32.3	58.4
McIntosh	11.9	6.0	21.3	48.9
Bottineau	17.0	16.5	36.6	49.5
Stutsman	15.9	12.7	30.9	41.4
Morton	14.4	7.6	28.0	42.1
Williams	16.0	7.5	37.3	35.4
McKenzie	16.0	9.0	36.6	34.6
Golden Valley	15.7	6.0	33.9	38.8

Table 5.3 Shows Nine Counties Two Critical Years 1988 and 1993 Average Spring Wheat Yield Compared with a Recent Year and a Period. Sources: Campbell 1987; USDA National Agricultural Statistic Service 2018; and North Dakota Wheat Commission 2019.

In a good year, average spring wheat yield in North Dakota is about 46 (bu/acre) (USDA 2016). Within the periods, North Dakota's average spring wheat yield was lower in the 1st period, when average high temperatures were more than the optimum spring wheat growing temperature. In 1988, the most affected counties were Golden Valley, McIntosh, Williams, Morton, and McKenzie with yields (bu/acre) at 6 (bu/acre), 6 (bu/acre), 7.5 (bu/acre), 7.6 (bu/acre), and 9 (bu/acre), respectively. The most affected stations are located in south-central and western North Dakota where drier climate conditions makes soil less saturated. In a drought year, the additional temperature makes those regions vulnerable to lesser spring wheat yields. The counties in north-eastern and eastern sections of North Dakota experience moister climate and richer soil conditions resulting in higher spring wheat yields versus western and southern North Dakota. The spring wheat yield was higher in the north-east and eastern regions. The weather stations in north-eastern and eastern regions of North Dakota in 1988 experienced maximum temperatures higher than ideal while precipitation was lower than normal.

Over the ten years, between 1986 and 1995, North Dakota experienced a dry and a wet year. The dry year was in the 1st period (1986-1990), 1988, and the wet year was in the 2nd period (1991-1995), 1993. Over the short term, there had been a climate pattern observed that approximately every five years a wet year followed a dry year. Although this study focused on a shorter time period, a future study over a longer time period may observe a similar pattern.

Producing about 50 bushels per acre, spring wheat has a water requirement equivalent to about 10 inches. Since water evaporates from the soil surface, the actual amount of water needed to produce a crop is higher. Under North Dakota climate conditions, wheat needs 14 to 16 inches of soil moisture per season (Climate of North Dakota 2018), depending on climactic conditions, production system, and the length of the growing season. In wetter circumstances, the spring wheat yield pattern is different in North Dakota. However, excessive water could cause root disease that kills roots and leaves in early development of plants as mentioned earlier (Wiersma and Ransom 2005). In wet year, 1993, all nine counties received optimum temperature and precipitation. According to *The Small Grains Field Guide* (Wiersma and Ransom 2005), all counties wheat yield should be about 50 bushels per acre, but yield ranged from 31.3 to 37.3 bushels per acre. In 1993, the overall wheat production was higher in western and central North Dakota than eastern North Dakota. Increase in spring wheat yield in western and central North during 1993 wet conditions compensated for drier climate conditions similar to central and western North Dakota. On the other, Grand Forks and Cass counties spring wheat yield remained lower than optimal. McIntosh County's yield was the worst among the nine counties in month of June: the precipitation received was 8.18 inches. If the ground already stored enough water, too much water may cause destroyed plant roots and leaves. As a result, the spring wheat yield did not reach optimum level.

5.4 Overall Summaries for Maximum Temperature, Precipitation, and Spring Wheat Yield for 1988 and 1993

As mentioned earlier, dry and wet years had been observed during the two periods. After analyzing the results, it indicates that the north and the east side of North Dakota are appropriate locations for spring wheat yield during both dry and wet periods. However, extreme weather events are harmful because these events could reduce overall North Dakota spring wheat yield. Table 5.4 illustrates that in 1988 the average maximum temperatures for the nine weather stations were above 84ºF. Total precipitation amounts received were between 1.41 inches to 6.41 inches, and the spring wheat yield was between 6 to 26.7 (bu/acre). On the other hand, in 1993 the average maximum temperatures for the nine weather stations were below 76ºF. Total precipitation received were between 12. 56 inches and 20.80 inches, while the spring wheat yield was between 21.3 and 37.3 (bu/acre) (Table 5.4). Closer observation of the data helps to explain that 1988 was a drought condition that caused decreased spring wheat yield. However, 1993 was a wet year. Thus, some regions received more precipitation than others; yet areas being too wet resulted in lower spring wheat yield in certain counties. These results indicate that higher precipitation has a potential for both positive and negative impacts on spring wheat yield.

	Regions	Counties	Weather Stations	Tmax (°F) 1988	Precip (in) 1988	Yield (bu/acre)	Tmax (°F) 1993	Precip (in) 1993	Yield (bu/acre)
Eastern ND	North East	Grand Forks	Grand Forks	85.1	6.41	26.7	74.81	16.98	33
	East Central	Cass	Fargo	87.5	3.84	19.1	76.62	13.12	32.3
	South East	McIntosh	Ashley	87.9	3.69	6	73.62	20.51	21.3
Central ND	North Central	Bottineau	Bottineau	84.4	5.09	16.5	71.95	12.56	36.6
	Central	Stutsman	Jamestown	88.0	4.8	12.7	73.37	20.8	30.9
	South Central	Morton	Mandan	87.5	5.66	7.6	73.98	19.79	28
Western ND	North West	Williams	Wildrose	84.5	5.15	7.5	71.24	13.66	37.3
	West Central	McKenzie	Keene 3 S	89.36	3.78	9	72.97	14.78	36.6
	South West	Golden Valley	Trotters	89.7	1.41	6	72.48	14.48	33.9

Table 5.4 Showing Maximum Temperatures, Precipitation, and Spring Wheat Yield for Nine Regions, Counties, and Weather Stations for 1988 and 1993. Sources: NOAA and NASS

In 1988, eastern North Dakota's average maximum temperature was higher than central North Dakota. However, spring wheat yield was higher in eastern North Dakota than central North Dakota. During 1993, eastern North Dakota‘s total precipitation received was more than that of western North Dakota, but spring wheat yield was more than western and central North Dakota. The yield differentiations appear depending on geographic locations, landscapes, and climate events. As mentioned earlier, North Dakota is positioned at the center of the North American continent and has three distinct regions: the Red River Valley, the Drift Prairie, and the Missouri Plateau. As they go from east to west, the elevation increases and climate changes from wet to drier conditions. Each region's soil fertility is different which also determines the type of agricultural activities that are carried out in each region. The Red River Valley has the richest soil, which might benefit the region during extreme weather events.

The hypothesis of this study says that with an increase in temperature, spring wheat yield will decrease, but an increase of precipitation provides an increase in spring wheat yield. Nonetheless, the results do not completely match the hypothesis. The result shows that during drought conditions the spring wheat yield decreased in nine counties. With an increase of precipitation the spring wheat yield varies, with some yield increases and some decreases across the counties in the study.

Referring to Figure 5.4, the climate change projections model is showing the scenarios if global mean temperature increases by 4ºC or more and how an increase of temperature will have impacts on cropping systems for tropical and temperate regions. This model indicates that in a twenty-year interval timeframe (2010-2029) the increase and the decrease in cropping yield is similar in the short term; nevertheless, the 2010-2109 timeframe is long term and projects that the crop yield will decrease from 5% to 100% in tropical and temperate regions (IPCC 2014).

This particular model gives an idea of what future crop production will resemble, including spring wheat. Globally, the climate change phenomenon should consider wheat as an important issue that needs resolution. The continuation of long-term climate change increases the risks associated with extreme climate events like severe droughts and extreme rainfall. As a result, the major small grain crops (wheat, rice, and maize) in most of the tropical and temperate regions would experience large risks to food security globally and regionally, including North Dakota.

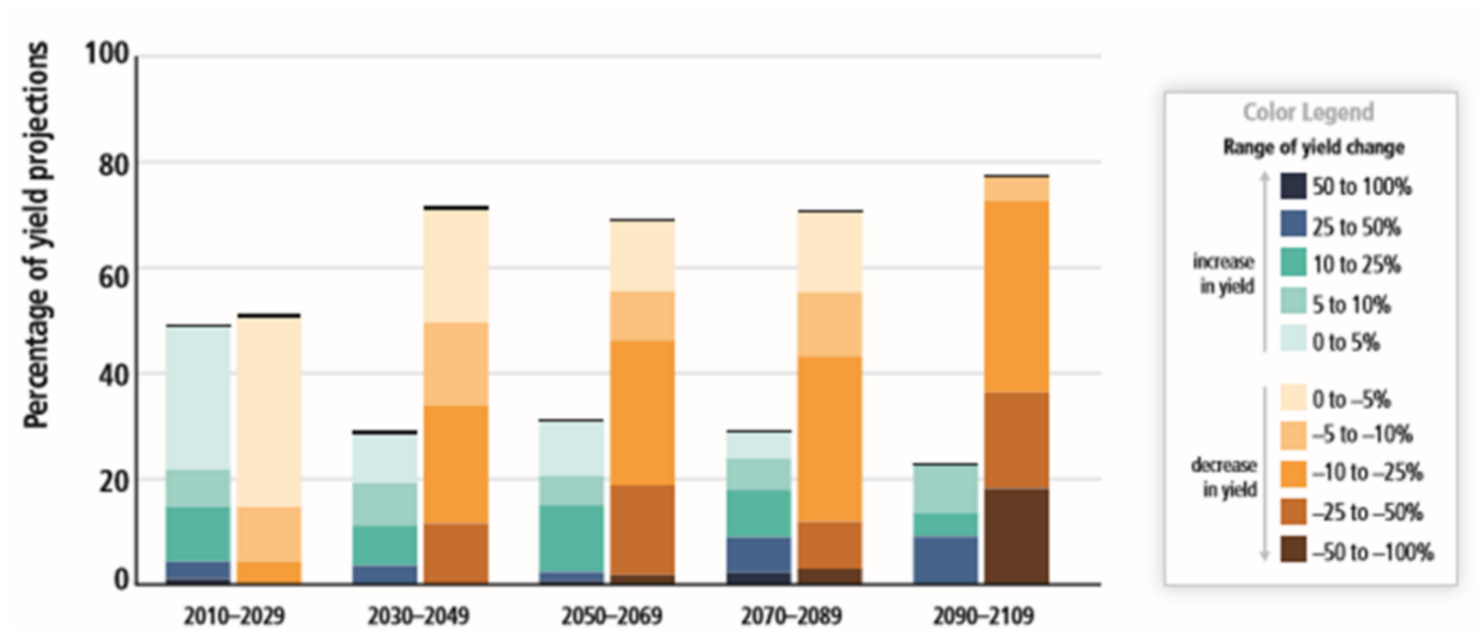


Figure 5.5 Summary for Policymakers Study on Future Risks and Impacts Caused by a Changing Climate Model Showing Projections for 2109 Crop Yield. Source: IPCC 2014

Coping with these extreme temperature and rainfall events are necessary when attempting to increase spring wheat yield in North Dakota. Food producers have important questions to consider including how to recognize the root causes of extreme climate events, when to consider drought and frost-resistant seeds, which cultivation methods are appropriate in a changing climate, what is long-term sustainable development in terms of mitigation and adaptation, and what should be altered in climate change policies. Following this chapter, the conclusions are presented regarding this research.

CHAPTER 6

CONCLUSION

Worldwide, many people consume a large portion carbohydrates for their daily diet, and wheat is one of the major crops that helps to meet the world demand for daily nutrients. The global population has been increasing at an exponential rate since the industrial period. The world population reached 7 billion in 2012, and the current world population is 7.7 billion. It is projected to reach more than 9 billion by 2050 (FAO 2019; U.S. Census Bureau 2019). As population grows, the demand for food also increases. This presents challenges in meeting global food demand. At the same time, the global climate has been changing, which leads to extreme climate events. As a result of climate change, there has been an increase in extreme events such as widely fluctuating temperatures, heat waves, excessive precipitation, drought, and floods. These extreme events are found regionally. Because these extreme events have brought various changes in temperature and precipitation, such conditions could affect the growth of crops such as spring wheat and its yield in North Dakota.

The United States depends on wheat for carbohydrates, and North Dakota is one of its major wheat producers. Wheat also plays a main role in North Dakota's economy. This study was undertaken to consider if there was any relationship between temperature, precipitation, and spring wheat yield in the periods of 1986-1990 and 1991-1995 in North Dakota. A total of 53 North Dakota counties were divided into nine agricultural regions. Nine counties and nine weather stations were selected to measure and compare temperature, precipitation, and spring wheat yield across North Dakota.

The results showed that it is not certain an increase of precipitation would provide an increase in spring wheat yield. Some yields were higher and some were lower. The findings indicate that warmer temperatures and drought conditions are detrimental to spring wheat production in comparison to heavy precipitation and wet conditions. Overall, North Dakota spring wheat yield relies on inter-annual variability in temperature and precipitation with yield being impacted significantly by temperature and precipitation variability.

The current traits in population growth, food demand, temperature, and precipitation pattern change mostly hurts developing countries. North Dakota should continue producing high-quality spring wheat; thus, an increase in spring wheat is beneficial to North Dakota's economy and supports the global spring wheat market, which helps fill the gap in global food scarcity.

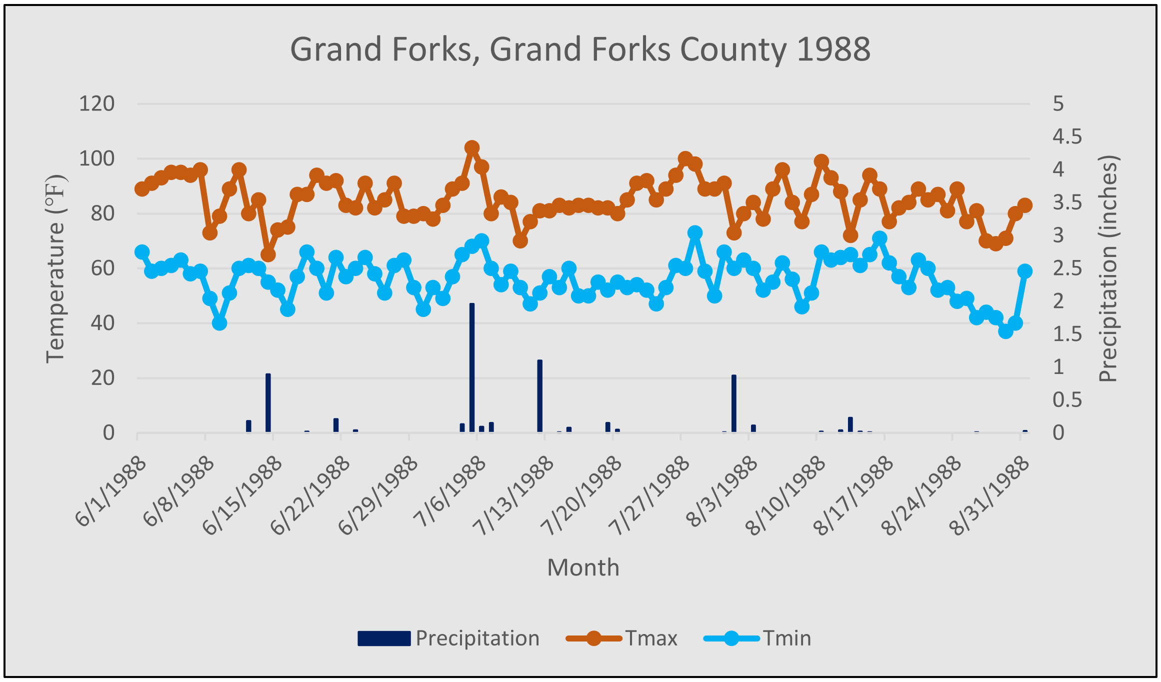
Future global food insecurity could be prevented by considering adaptation strategies for maintaining substantial crop yields (Asseng 2011). Therefore, we need to develop climate-resistant seeds, adjust growing seasons, and improve agricultural technology. In addition, global climate policy makers, government leaders, farmers, economists, and businesses leaders must work together to increase productivity in crops.

Bayer is a pharmaceutical advance leader that claims the improvements are already made in agriculture by continuing to invent herbicide, insecticide, seed, and fungicide and seed treatment technologies to help maximize spring wheat yield and performance from start to finish (Bayer 2017). Instead, global climate change stand point, farmers should consider adapting organic crop farming, no-till farming system, and sustainable farming practices to increase crop yield beyond money and ethics. These farming systems will contribute to reduce use of pesticides and chemicals, improve soil quality, pest and weed management, and conservation of soil and water. Furthermore, these practices would support fighting the effects of global climate change. Both the theoretical and empirical framework of this research will benefit for future studies in regard to North Dakota's HRS wheat yield.

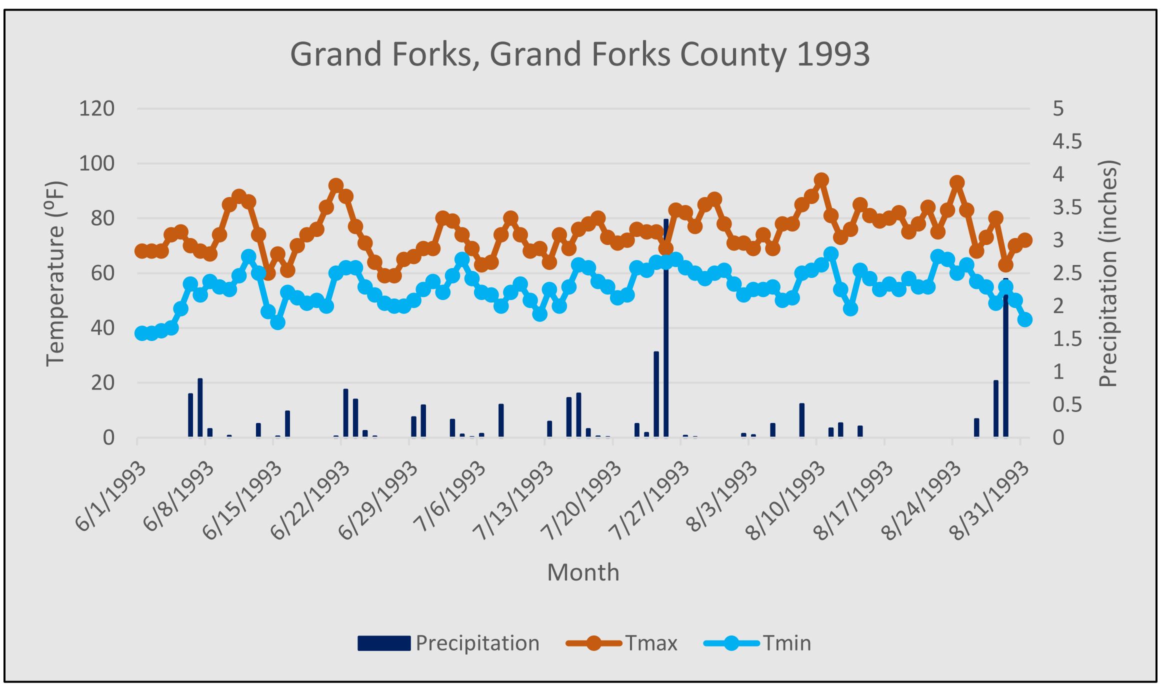
Overall, findings from this study illustrate the State of North Dakota spring wheat yield is impacted significantly with drought conditions and with an increase in precipitation. In some areas yield increases and some areas yield decreases. Both temperature and precipitation extremes are harmful to spring wheat yield in varying degrees.

APPENDICES

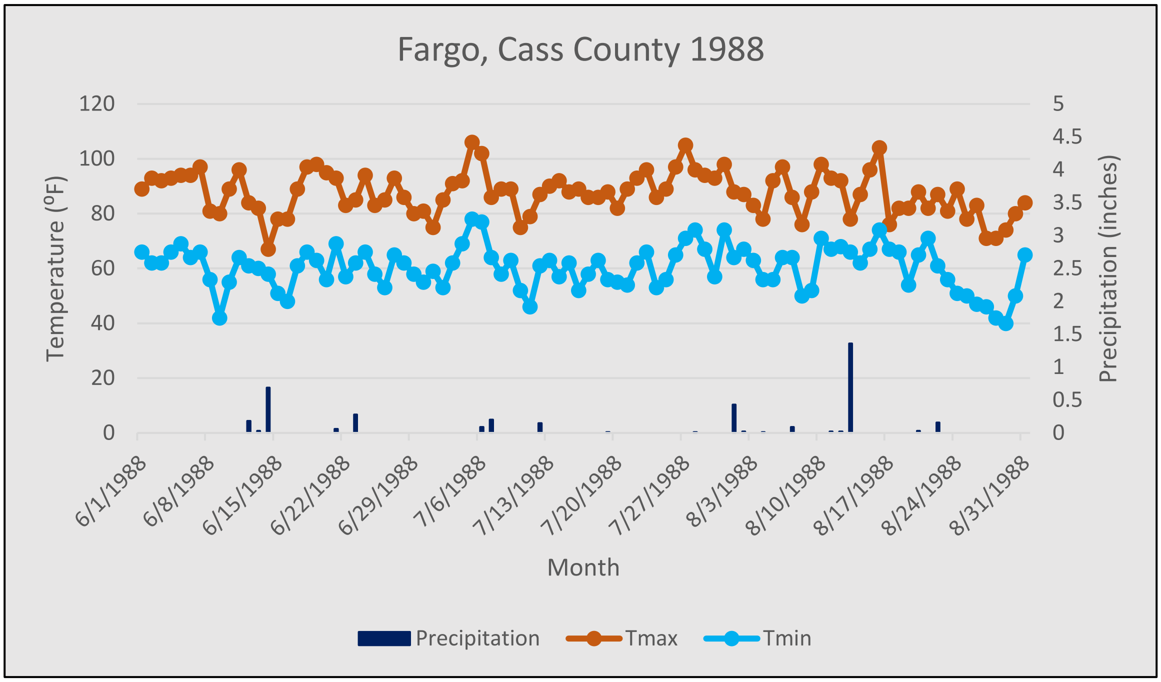
Appendix A



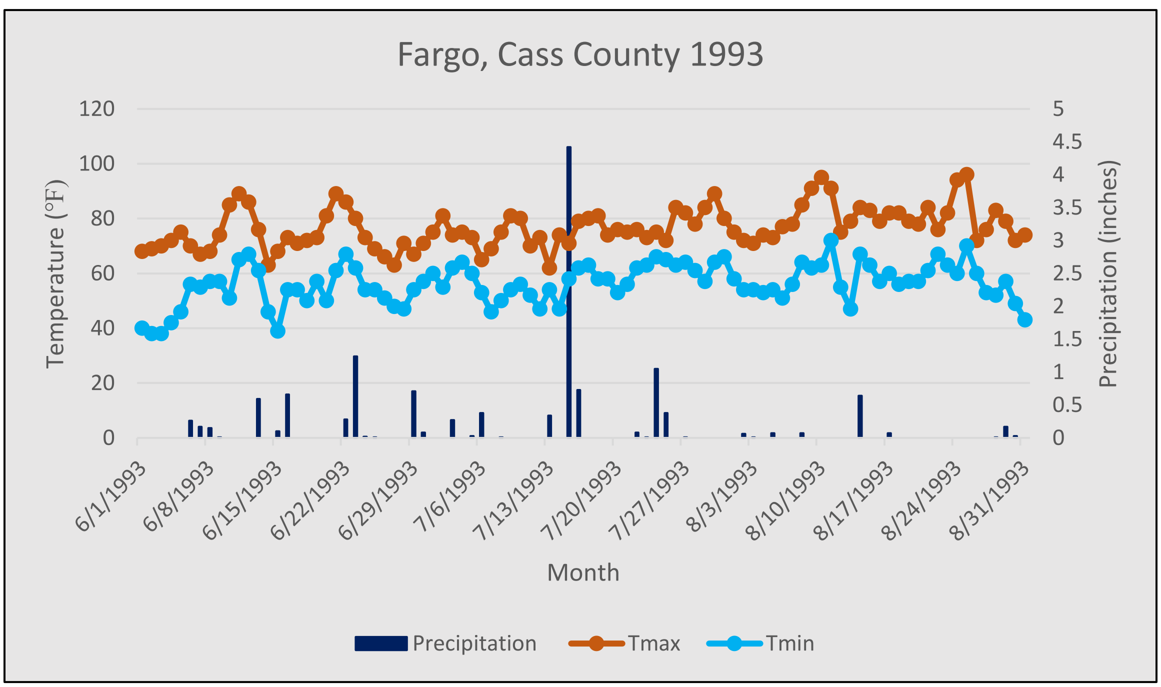
Climograph of Temperature and Precipitation for Grand Forks, 1988. Source: NOAA



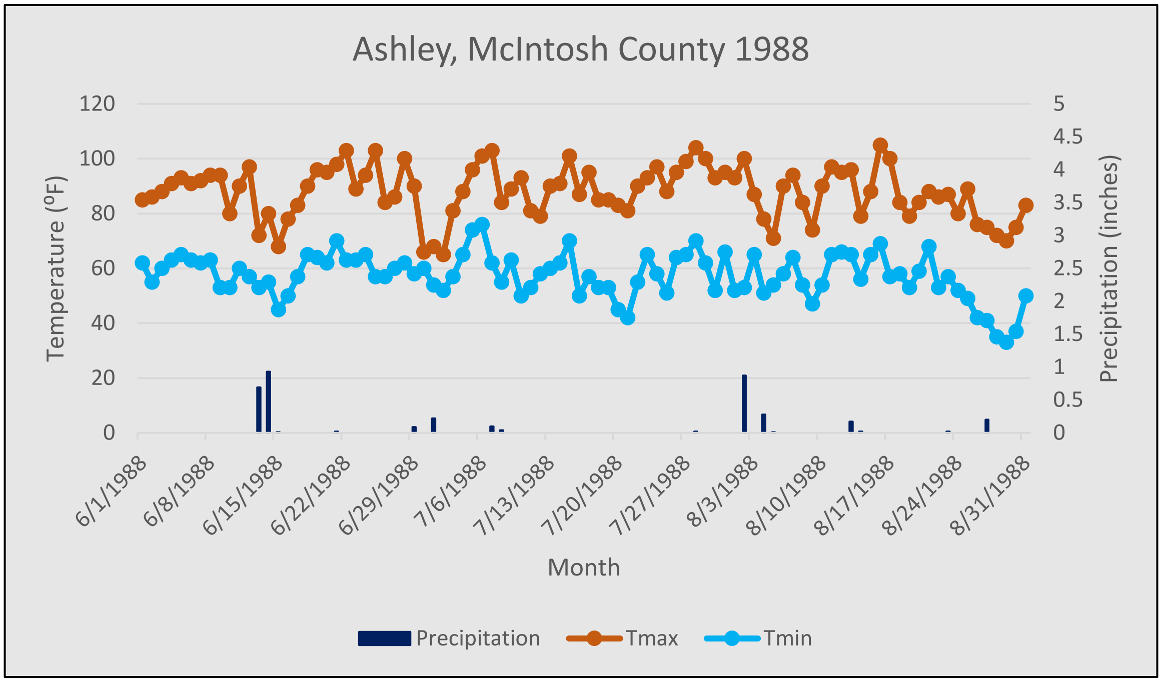
Climograph of Temperature and Precipitation for Grand Forks, 1993. Source: NOAA.



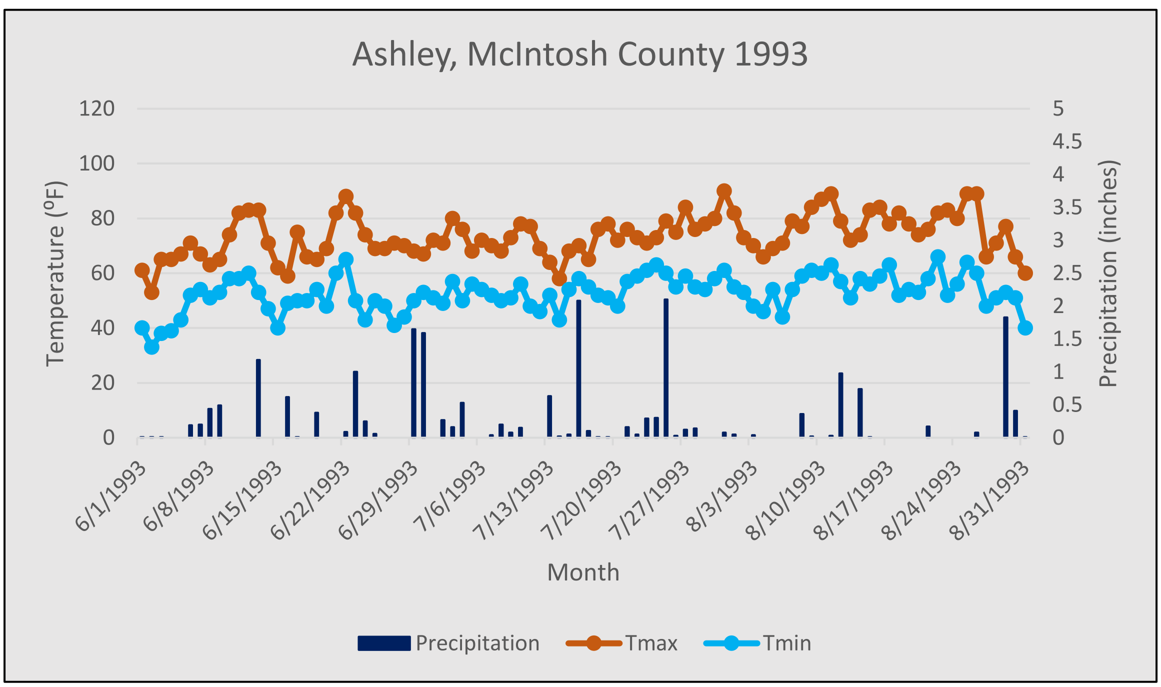
Climograph of Temperature and Precipitation for Fargo, 1988. Source: NOAA



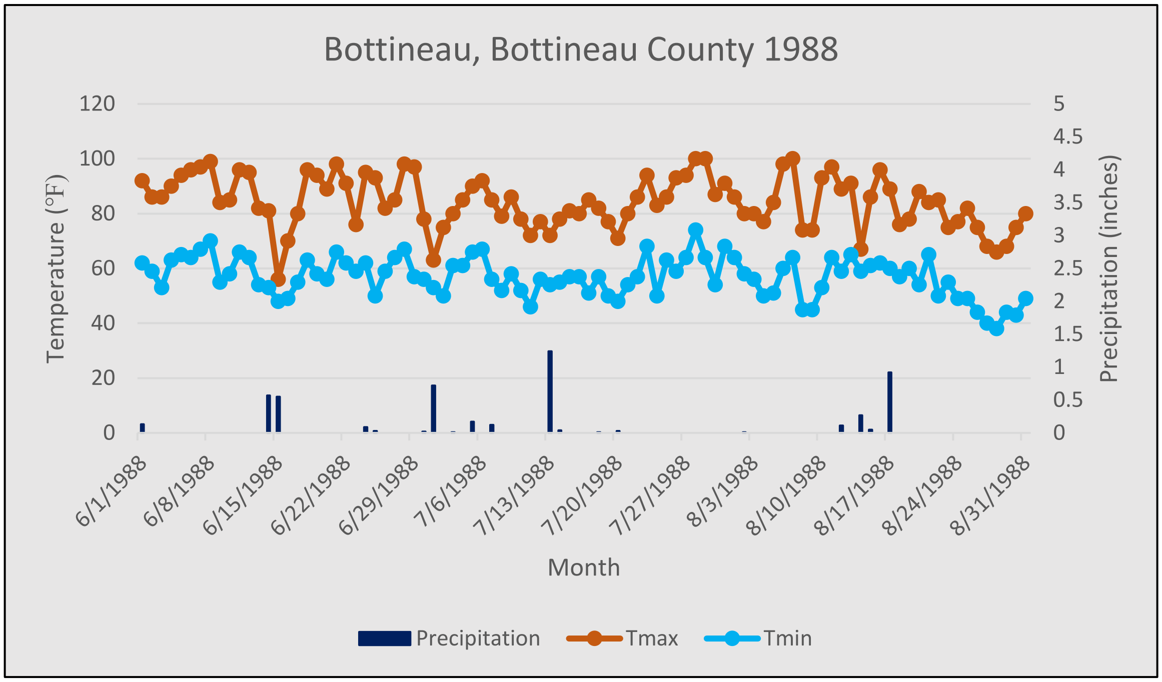
Climograph of Temperature and Precipitation for Fargo, 1993. Source: NOAA.



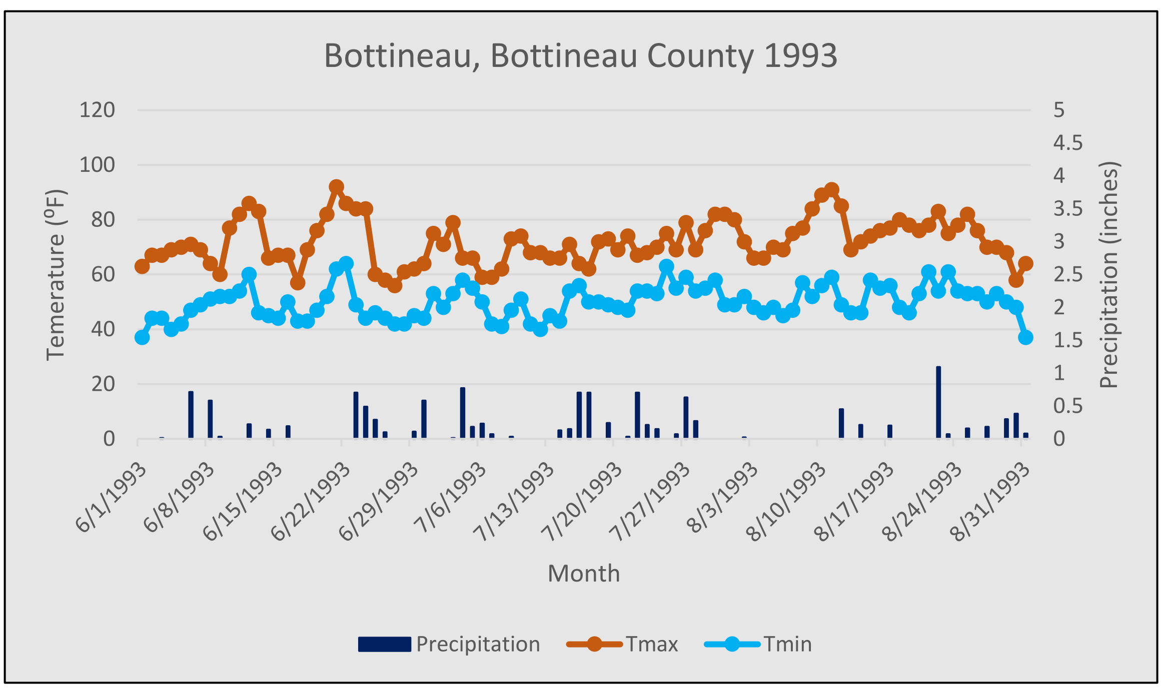
Climograph of Temperature and Precipitation for Ashley, 1988. Source: NOAA



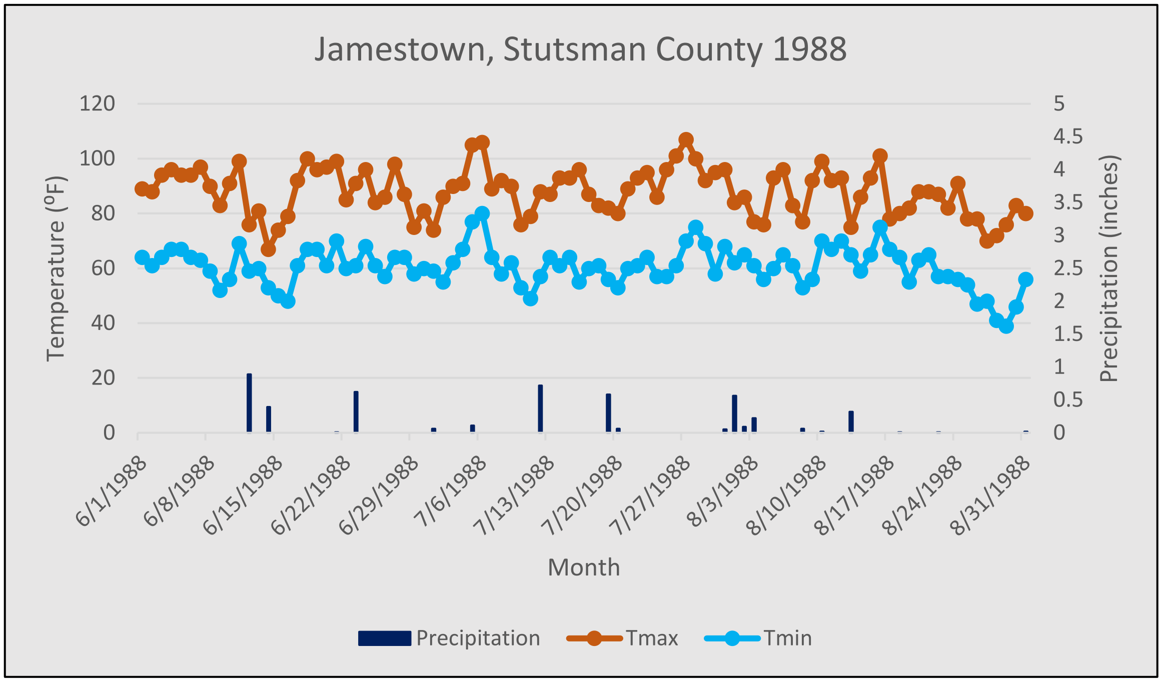
Climograph of Temperature and Precipitation for Ashley, 1993. Source: NOAA.



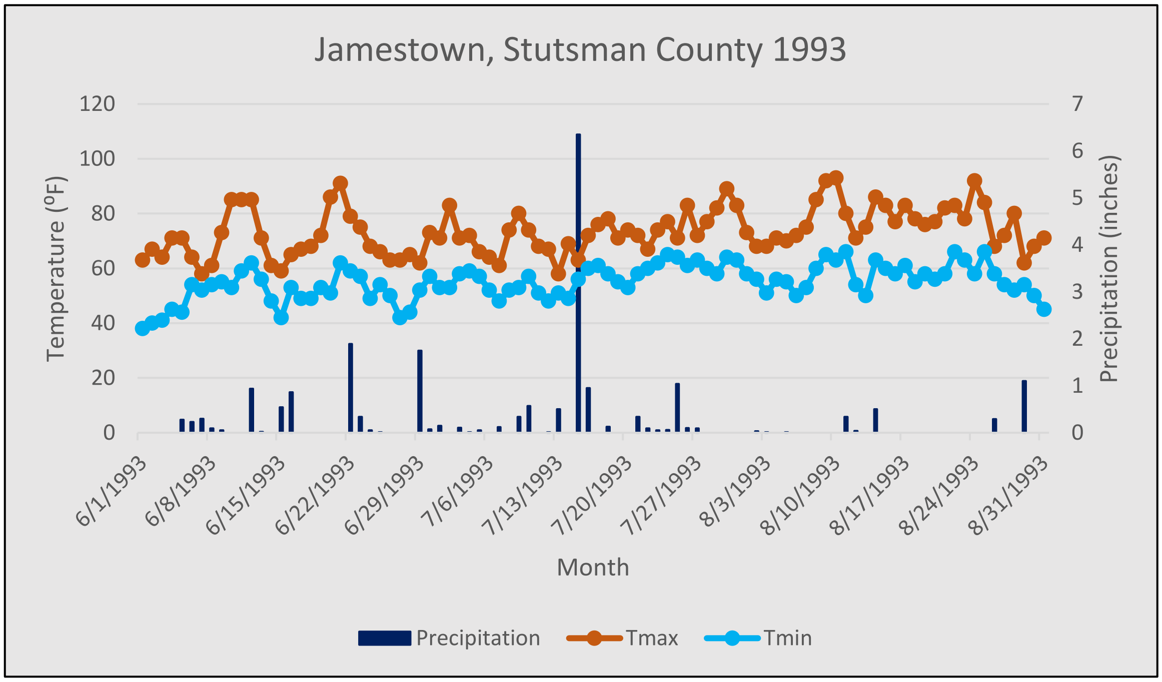
Climograph of Temperature and Precipitation for Bottineau, 1988. Source: NOAA



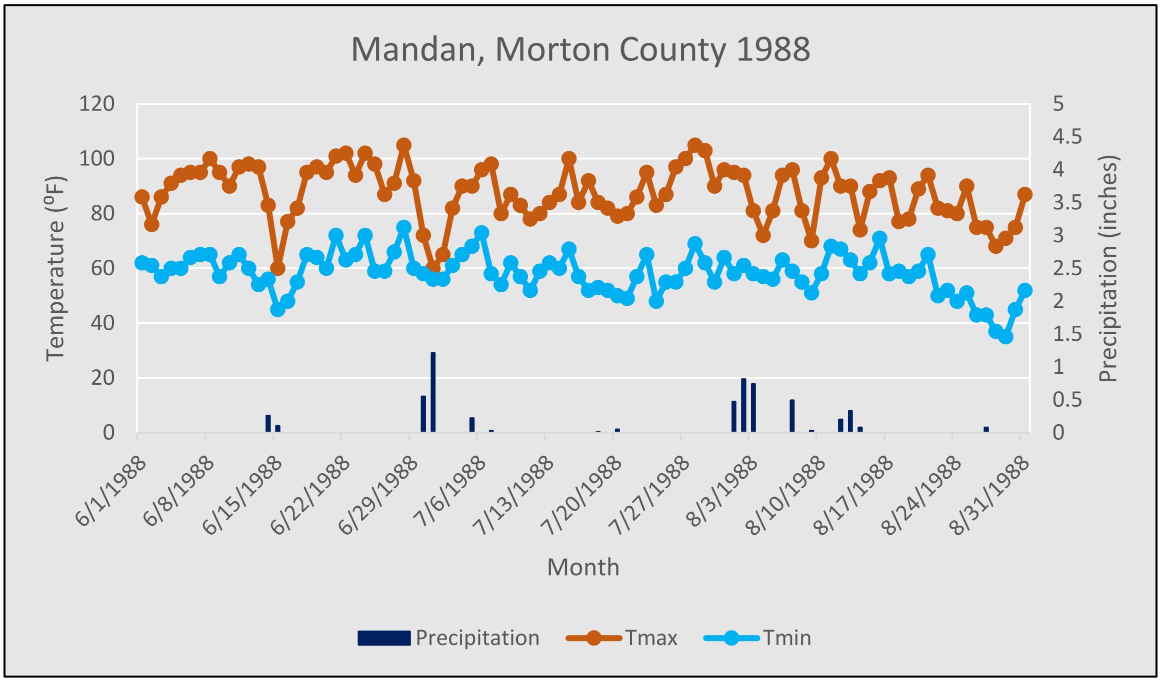
Climograph of Temperature and Precipitation for Bottineau, 1993. Source: NOAA.



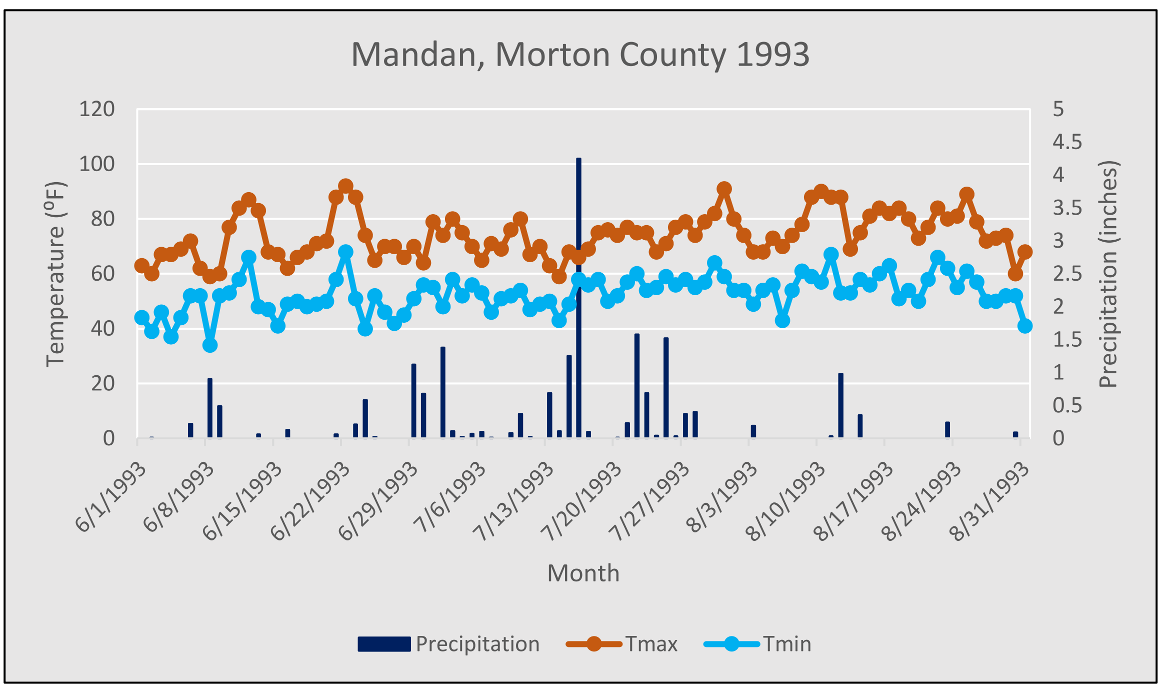
Climograph of Temperature and Precipitation for Jamestown, 1988. Source: NOAA



Climograph of Temperature and Precipitation for Jamestown 1993. Source: NOAA.



Climograph of Temperature and Precipitation for Mandan, 1988. Source: NOAA



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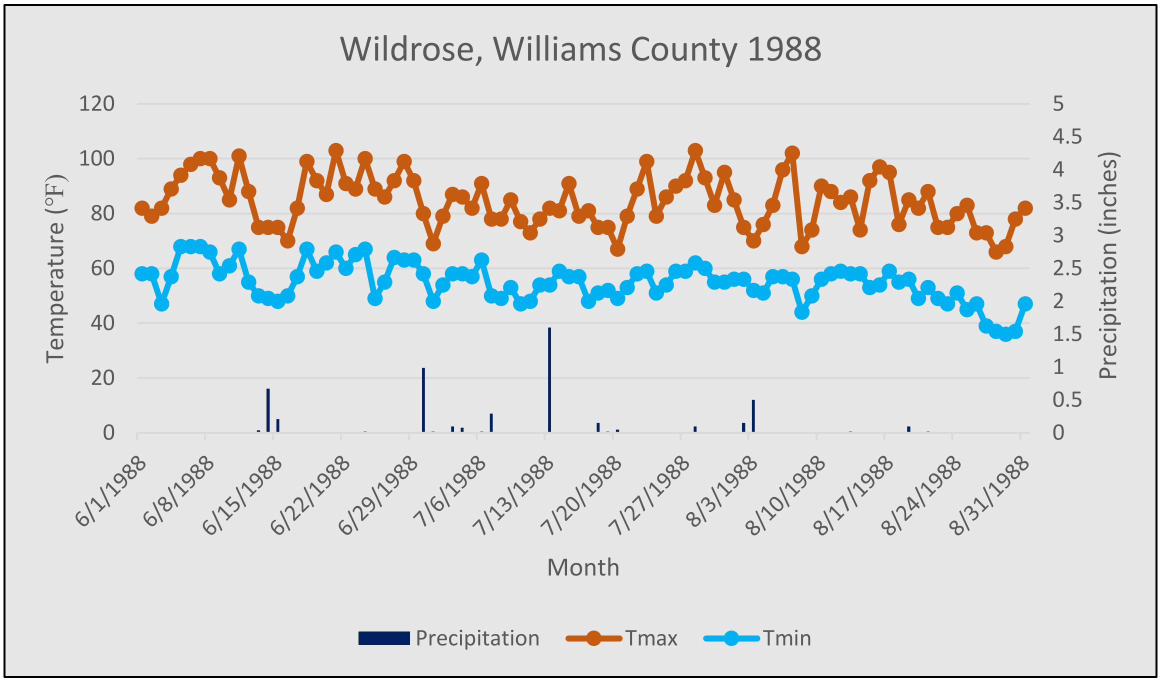
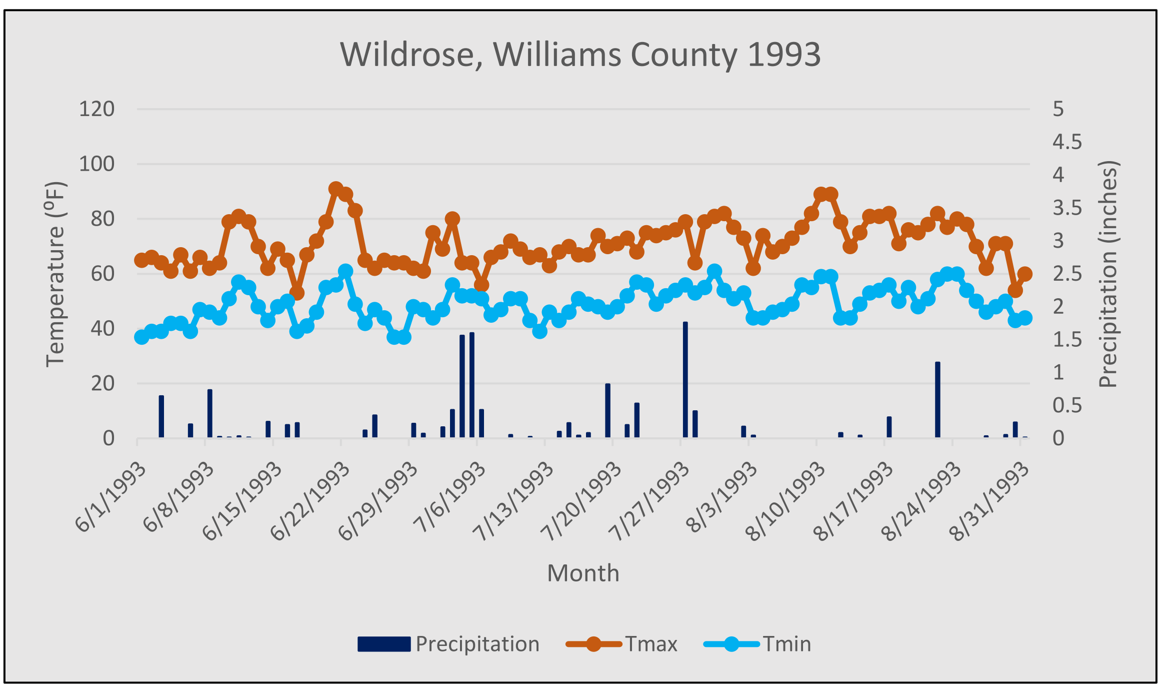


Climograph of Temperature and Precipitation for Wildrose, 1988. Source: NOAA



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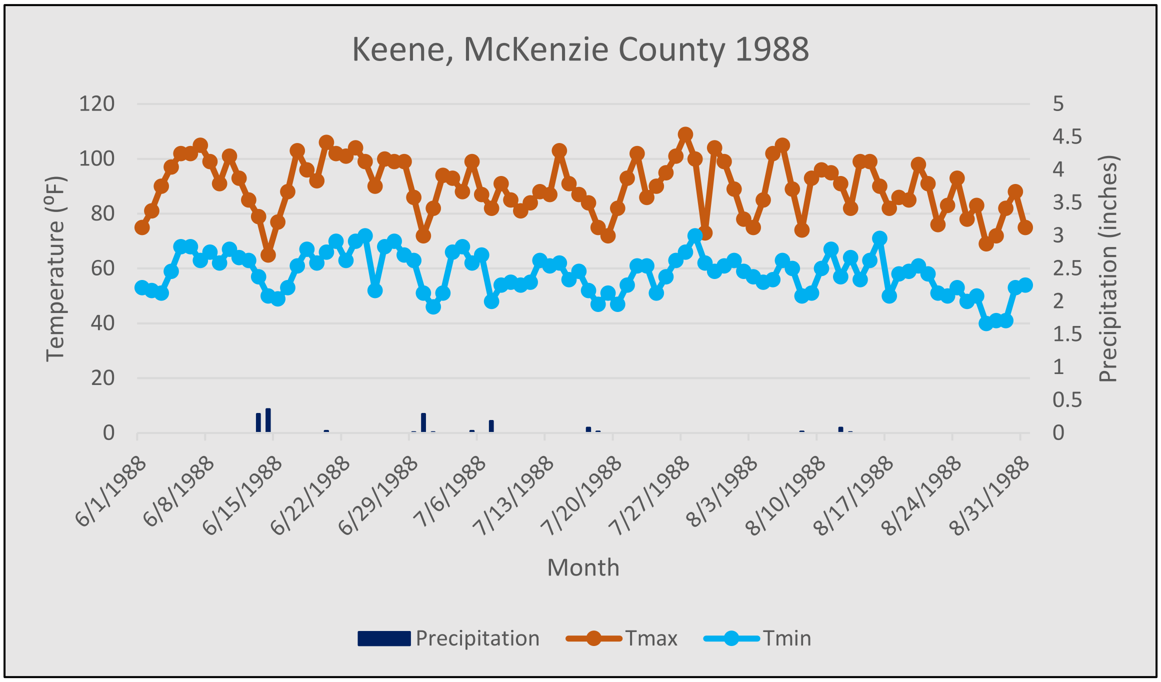
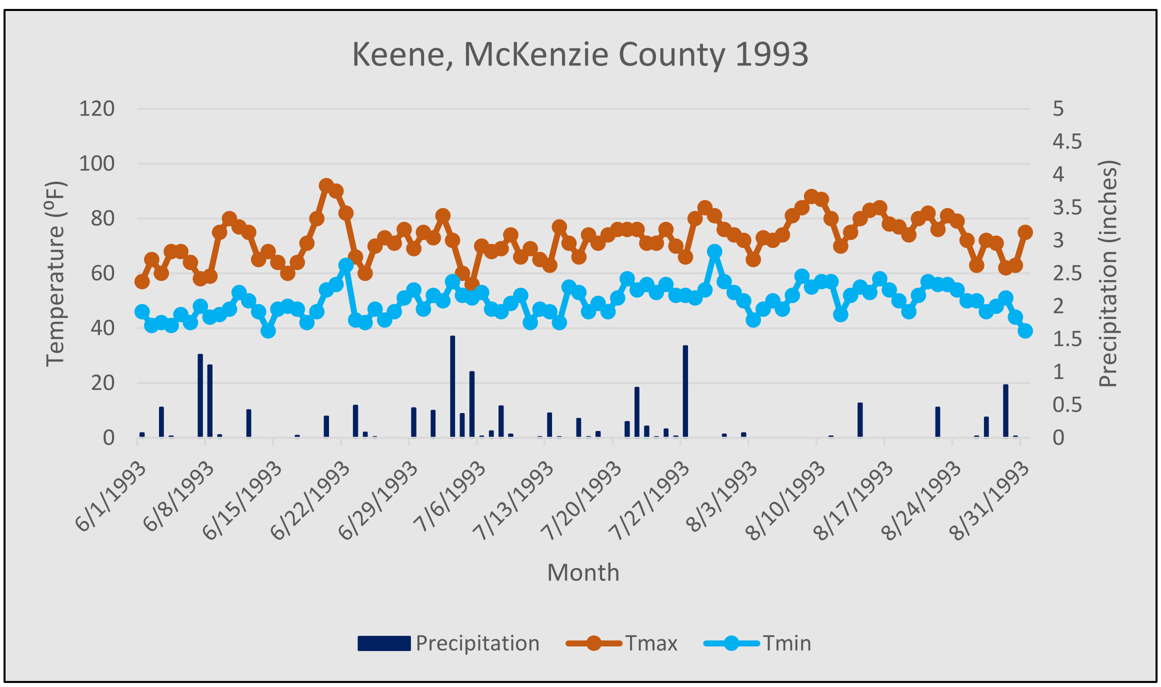


Climograph of Temperature and Precipitation for Keene 3 S, 1988. Source: NOAA



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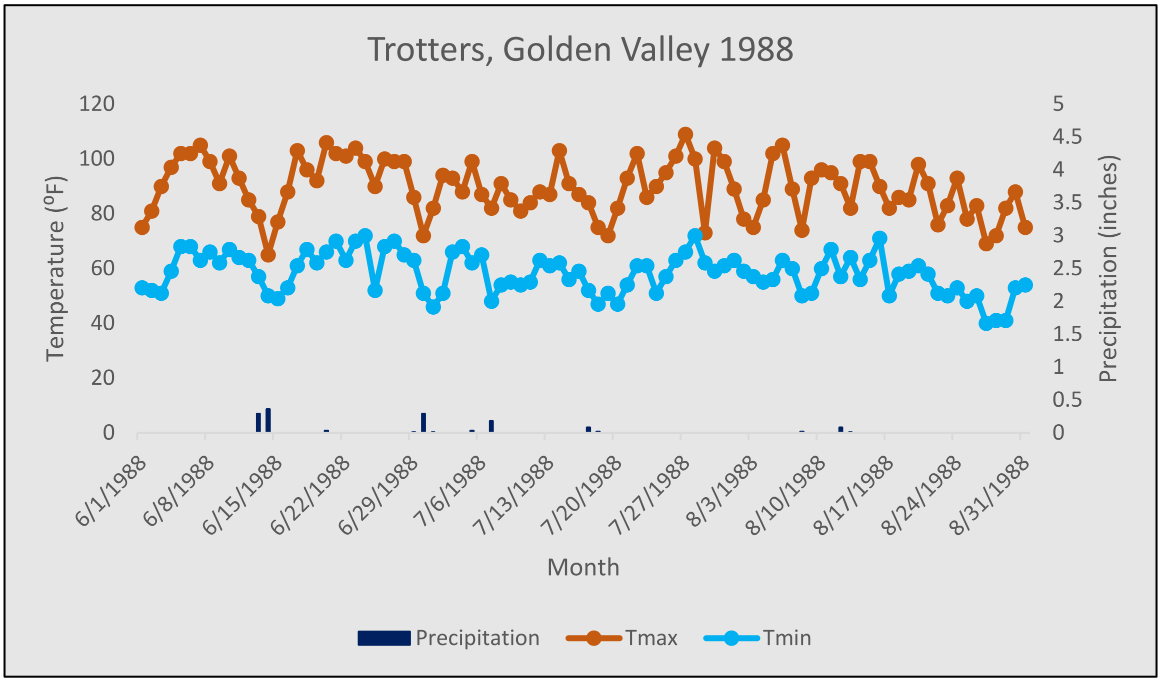
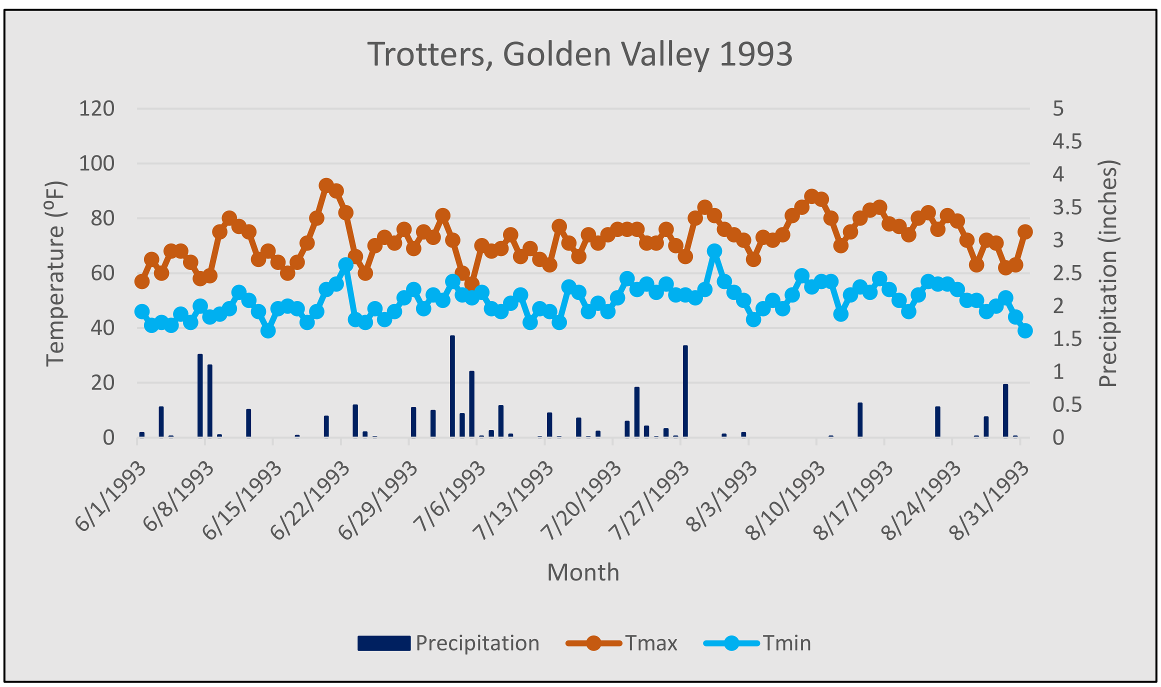


Climograph of Temperature and Precipitation for Trotters, 1988. Source: NOAA



Climograph of Temperature and Precipitation for Trotters, 1993. Source: NOAA.

	A	B	C	D	E	F	K	L	M	N	O	P	Q	R
1	STATION	NAME	LATITUDE	LONGITUDE	ELEVATIO	DATE	PRCP	SNOW	SNWD	TAVG	TMAX	TMIN	TOBS	
2	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/1/1950	0	0	0		65	38	49	
3	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/2/1950	0.09	0	0		52	34	46	
4	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/3/1950	0	0	0		59	28	48	
5	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/4/1950	0	0	0		84	48	72	
6	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/5/1950	0	0	0		75	48	57	
7	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/6/1950	0	0	0		82	43	53	
8	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/7/1950	0.02	0	0		56	45	52	
9	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/8/1950	1.35	0	0		55	45	48	
10	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/9/1950	0.09	0	0		54	37	51	
11	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/10/1950	0	0	0		74	43	65	
12	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/11/1950	0	0	0		81	49	71	
13	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/12/1950	0	0	0		82	59	80	
14	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/13/1950	0	0	0		81	57	64	
15	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/14/1950	0.09	0	0		86	55	66	
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27	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	6/26/1950	0.16	0	0		71	48	71	
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34	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	7/3/1950	0.01	0	0		68	53	62	
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38	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	7/7/1950	0.01	0	0		84	59	74	
39	USC00320941	BOTTINEAU, ND US	48.8216	-100.4527	493.5	7/8/1950	0.09	0	0		84	64	78	

Bottineaw

A Sample of Weather Data Collection. Source: NOAA

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	YEAR	LOCATION	STATE AN	ASD CODE	COUNTY A	REFERENC	COMMOD	AREA HAR	AREA HAR	AREA HAR	AREA HAR	AREA PLA	AREA PLA	AREA PLA	AREA PLA	PRODUCTION in BU	PRODUCTI	PRODUCTI	PRODUCTI	YIELD, SPF	YIELD in BI	YIELD, WII	YIELD, SPF	YIELD, WII	YIELD in BI
2	1986	NORTH DAKOTA, CENTRAL, EDDY	38	50	27	YEAR	WHEAT	7,500	10,500	70,000	88,000	8,000	89,500	11,500	70,000	2,489,000	214,000	315,000	1,960,000	28.5	28.3	30	28	27.4	27.8
3	1986	NORTH DAKOTA, CENTRAL, FOSTER	38	50	31	YEAR	WHEAT	13,000	9,800	104,000	126,800	14,000	130,000	11,000	105,000	3,995,500	344,000	323,500	3,328,000	26.5	31.5	33	32	29.4	30.7
4	1986	NORTH DAKOTA, CENTRAL, KIDDER	38	50	43	YEAR	WHEAT	7,000	1,800	90,000	98,800	8,000	100,000	2,000	90,000	2,104,000	133,000	36,000	1,935,000	19	21.3	20	21.5	18	21
5	1986	NORTH DAKOTA, CENTRAL, SHERIDAN	38	50	83	YEAR	WHEAT	5,500	5,500	109,000	120,000	6,000	122,000	6,000	110,000	3,332,500	165,000	115,500	3,052,000	30	27.8	21	28	19.3	27.3
6	1986	NORTH DAKOTA, CENTRAL, STUTSMAN	38	50	93	YEAR	WHEAT	89,000	27,400	267,000	383,400	95,000	394,500	29,500	270,000	11,795,000	2,667,000	768,000	8,360,000	30	30.8	28	31.3	26	29.9
7	1986	NORTH DAKOTA, CENTRAL, WELLS	38	50	103	YEAR	WHEAT	38,000	18,000	165,000	221,000	39,000	224,000	20,000	165,000	6,834,000	1,197,000	522,000	5,115,000	31.5	30.9	29	31	26.1	30.5
8	1986	NORTH DAKOTA, EAST CENTRAL, BARNES	38	60	3	YEAR	WHEAT	15,500	28,000	239,000	282,500	17,000	287,000	30,000	240,000	8,983,000	488,000	966,000	7,529,000	31.5	31.8	34.5	31.5	32.2	31.3
9	1986	NORTH DAKOTA, EAST CENTRAL, CASS	38	60	17	YEAR	WHEAT	22,000	9,400	276,000	307,400	25,000	315,000	10,000	280,000	10,410,600	715,000	366,600	9,329,000	32.5	33.9	39	33.8	36.7	33
10	1986	NORTH DAKOTA, EAST CENTRAL, GRIGGS	38	60	39	YEAR	WHEAT	7,000	9,500	95,000	111,500	7,500	112,500	10,000	95,000	3,281,000	175,000	304,000	2,802,000	25	29.4	32	29.5	30.4	29.2
11	1986	NORTH DAKOTA, EAST CENTRAL, STEELE	38	60	91	YEAR	WHEAT	4,500	3,400	115,000	122,900	4,500	123,500	4,000	115,000	4,412,000	153,000	119,000	4,140,000	34	35.9	35	36	29.8	35.7
12	1986	NORTH DAKOTA, EAST CENTRAL, TRAILL	38	60	97	YEAR	WHEAT	6,000	700	140,000	146,700	6,000	147,000	1,000	140,000	5,356,400	147,000	29,400	5,180,000	24.5	36.5	42	37	29.4	36.4
13	1986	NORTH DAKOTA, NORTH CENTRAL, BENSON	38	20	5	YEAR	WHEAT	140,000	2,900	70,000	212,900	145,000	218,000	3,000	70,000	6,098,300	4,130,000	78,300	1,890,000	29.5	28.6	27	27	26.1	28
14	1986	NORTH DAKOTA, NORTH CENTRAL, BOTTINE	38	20	9	YEAR	WHEAT	215,000	6,500	105,000	326,500	220,000	332,000	7,000	105,000	11,506,000	7,558,000	221,000	3,727,000	35.2	35.2	34	35.5	31.6	34.7
15	1986	NORTH DAKOTA, NORTH CENTRAL, MCHENR	38	20	49	YEAR	WHEAT	27,000	5,800	150,000	182,800	31,000	187,000	6,000	150,000	5,219,200	824,000	157,200	4,238,000	30.5	28.6	27.1	28.3	26.2	27.9
16	1986	NORTH DAKOTA, NORTH CENTRAL, PIERCE	38	20	69	YEAR	WHEAT	62,000	2,800	90,000	154,800	64,000	157,000	3,000	90,000	3,971,500	1,643,000	78,500	2,250,000	26.5	25.7	28	25	26.2	25.3
17	1986	NORTH DAKOTA, NORTH CENTRAL, ROLETTE	38	20	79	YEAR	WHEAT	106,000	1,000	25,000	132,000	110,000	136,000	1,000	25,000	4,355,000	3,445,000	35,000	875,000	32.5	33	35	35	35	32
18	1986	NORTH DAKOTA, NORTHEAST, CAVALIER	38	30	19	YEAR	WHEAT	112,000	500	210,000	322,500	120,000	330,500	500	210,000	11,467,000	3,472,000	15,000	7,980,000	31	35.6	30	38	30	34.7
19	1986	NORTH DAKOTA, NORTHEAST, GRAND FORK	38	30	35	YEAR	WHEAT	12,000	3,200	225,000	240,200	12,000	240,500	3,500	225,000	9,401,000	450,000	128,000	8,823,000	37.5	39.1	40	39.2	36.6	39.1
20	1986	NORTH DAKOTA, NORTHEAST, NELSON	38	30	63	YEAR	WHEAT	77,000	2,600	125,000	204,600	79,000	207,000	3,000	125,000	6,339,400	2,272,000	67,400	4,000,000	29.5	31	25.9	32	22.5	30.6
21	1986	NORTH DAKOTA, NORTHEAST, PEMBINA	38	30	67	YEAR	WHEAT	1,000	1,000	240,000	242,000	1,000	242,000	1,000	240,000	9,444,000	44,000	40,000	9,360,000	44	39	40	39	40	39
22	1986	NORTH DAKOTA, NORTHEAST, RAMSEY	38	30	71	YEAR	WHEAT	158,000	1,800	105,000	264,800	165,000	277,000	2,000	110,000	8,016,600	4,661,000	48,600	3,307,000	29.5	30.3	27	31.5	24.3	28.9
23	1986	NORTH DAKOTA, NORTHEAST, TOWNER	38	30	95	YEAR	WHEAT	198,000	3,000	20,000	221,000	210,000	234,000	4,000	20,000	6,003,000	5,299,000	84,000	620,000	26.8	27.2	28	31	21	25.7
24	1986	NORTH DAKOTA, NORTHEAST, WALSH	38	30	99	YEAR	WHEAT	32,000	900	240,000	272,900	33,000	274,000	1,000	240,000	10,539,000	912,000	27,000	9,600,000	28.5	38.6	30	40	27	38.5
25	1986	NORTH DAKOTA, NORTHWEST, BURKE	38	10	13	YEAR	WHEAT	53,500	2,700	105,000	161,200	55,000	164,000	4,000	105,000	5,468,700	1,819,000	79,700	3,570,000	34	33.9	29.5	34	19.9	33.3
26	1986	NORTH DAKOTA, NORTHWEST, DIVIDE	38	10	23	YEAR	WHEAT	147,000	7,800	45,000	199,800	150,000	203,000	8,000	45,000	6,765,600	5,070,000	210,600	1,485,000	34.5	33.9	27	33	26.3	33.3
27	1986	NORTH DAKOTA, NORTHWEST, MOUNTRAIL	38	10	61	YEAR	WHEAT	173,000	4,500	55,000	232,500	175,000	235,000	5,000	55,000	8,769,300	6,569,000	137,300	2,063,000	38	37.7	30.5	37.5	27.5	37.3
28	1986	NORTH DAKOTA, NORTHWEST, RENVILLE	38	10	75	YEAR	WHEAT	64,500	2,400	115,000	181,900	65,000	182,500	2,500	115,000	6,776,000	2,225,000	66,000	4,485,000	34.5	37.3	27.5	39	26.4	37.1
29	1986	NORTH DAKOTA, NORTHWEST, WARD	38	10	101	YEAR	WHEAT	209,000	2,400	160,000	371,400	210,000	372,500	2,500	160,000	13,724,000	7,412,000	72,000	6,240,000	35.5	37	30	39	28.8	36.8
30	1986	NORTH DAKOTA, NORTHWEST, WILLIAMS	38	10	105	YEAR	WHEAT	83,000	25,200	190,000	298,200	85,000	303,000	28,000	190,000	9,368,400	2,820,000	581,400	5,967,000	34	31.4	23.1	31.4	20.8	30.9
31	1986	NORTH DAKOTA, SOUTH CENTRAL, BURLEIGH	38	80	15	YEAR	WHEAT	10,000	5,200	144,000	159,200	10,000	166,000	6,000	150,000	3,989,500	295,000	166,500	3,528,000	29.5	25.1	32	24.5	27.8	24
32	1986	NORTH DAKOTA, SOUTH CENTRAL, EMMONS	38	80	29	YEAR	WHEAT	3,500	4,500	171,000	179,000	4,400	184,400	5,000	175,000	3,831,000	73,000	126,000	3,632,000	20.9	21.4	28	21.2	25.2	20.8
33	1986	NORTH DAKOTA, SOUTH CENTRAL, GRANT	38	80	37	YEAR	WHEAT	2,300	6,100	98,000	106,400	2,400	114,400	7,000	105,000	2,653,000	63,000	189,000	2,401,000	27.4	24.9	31	24.5	27	23.2
34	1986	NORTH DAKOTA, SOUTH CENTRAL, MORTON	38	80	59	YEAR	WHEAT	1,200	4,400	118,000	123,600	1,900	136,900	5,000	130,000	3,770,000	30,000	141,000	3,599,000	25	30.5	32	30.5	28.2	27.5
35	1986	NORTH DAKOTA, SOUTH CENTRAL, SIOUX	38	80	85	YEAR	WHEAT	6,000	1,800	34,000	41,800	6,300	48,300	2,000	40,000	842,500	114,000	48,500	680,000	19	20.2	26.9	20	24.3	17.4
36	1986	NORTH DAKOTA, SOUTHEAST, DICKEY	38	90	21	YEAR	WHEAT	29,000	42,500	102,000	173,500	32,000	182,000	45,000	105,000	4,031,000	851,000	1,190,000	1,990,000	29.3	23.2	28	19.5	26.4	22.1
37	1986	NORTH DAKOTA, SOUTHEAST, LA MOURE	38	90	45	YEAR	WHEAT	19,200	32,500	127,000	178,700	24,000	189,000	35,000	130,000	4,579,000	461,000	943,000	3,175,000	24	25.6	29	25	26.9	24.2
38	1986	NORTH DAKOTA, SOUTHEAST, LOGAN	38	90	47	YEAR	WHEAT	5,300	5,800	89,000	100,100	6,700	103,200	6,500	90,000	2,615,000	143,000	158,000	2,314,000	27	26.1	27.2	26	24.3	25.3
39	1986	NORTH DAKOTA, SOUTHEAST, MCINTOSH	38	90	51	YEAR	WHEAT	11,000	3,400	116,000	130,400	13,000	136,500	3,500	120,000	2,868,000	231,000	85,000	2,552,000	21	22	25	22	24.3	21

WHEAT-AcreageYieldProductionand

A Sample of North Dakota Spring Wheat Data Collection. Source: USDA

Appendix B

Eastern North Dakota						
Grand Forks County						
Grand Forks International Airport Weather Station						
Date	Tmax ºF	Tmin ºF	Precip (in)	Bu/Acre	Acres Harvested	Acres planted
1986	79.5	55.0	6.36	39.2	225000	225000
1987	80.0	54.9	11.09	43	213000	215000
1988	85.1	56.3	6.41	26.7	216000	220000
1989	81.8	55.8	5.22	36	259500	260000
1990	80.2	55.6	8.09	49.5	280000	280000
1991	81.59	58.22	7.96	39.5	238000	240000
1992	73.94	51.76	7.92	54.7	289000	290000
1993	74.81	54.76	16.98	33	269000	290000
1994	78.07	55.71	12.89	34	275000	280000
1995	81.16	58.67	15.26	32.2	279000	280000
Cass County						
Fargo International Airport						
Date	Tmax ºF	Tmin ºF	Precip (in)	Bu/Acre	Acres Harvested	Acres planted
1986	79.3	57.0	10.48	33.8	276000	280000
1987	82.0	57.9	6.75	43	263000	265000
1988	87.5	60.3	3.84	19.1	248000	265000
1989	82.8	57.6	8.2	33.8	329000	330000
1990	81.2	57.5	7.82	51	378000	380000
1991	82.06	59.92	9.99	40.5	300000	300000
1992	74.66	52.64	9.65	49.4	406000	410000
1993	76.62	56.18	13.12	32.3	376000	400000
1994	78.25	56.58	11.14	36.1	375000	390000
1995	82.46	59.80	8.43	31.9	399000	400000
McIntosh County						
Ashley Weather Station						
Date	Tmax º F	Tmin ºF	Precip	Bu/Acre	Acres Harvested	Acres planted
1986	79.3	54.2	7.38	22	116000	120000
1987	81.4	55.9	9.81	22.5	121000	125000
1988	87.9	57.4	3.69	6	30500	120000
1989	82.3	55.3	9.11	14	131000	140000
1990	81.0	53.9	7.84	20	149000	150000
1991	80.82	56.88	8.63	26.5	123000	125000
1992	73.94	50.23	7.87	36.4	155000	155000
1993	73.62	52.66	20.51	21.3	136000	160000
1994	77.15	53.63	9.15	21.9	147000	150000
1995	79.53	57.82	10.48	19.3	119000	120000

Eastern North Dakota Selected Counties Maximum Temperature, Precipitation, and Spring Wheat Yield. Sources: NOAA; USDA (NASS).

Central North Dakota						
Bottineau County						
Bottineau Weather Stataion						
Date	Tmax	Tmin	Precipitation	Bu/Acre	Acres Harvested	Acres planted
1986	77.1	51.9	8.17	35.5	105000	105000
1987	77.4	53.2	11.25	28	92000	94000
1988	84.4	57.0	5.09	16.5	87500	92000
1989	79.7	54.0	7.31	26	140000	140000
1990	79.4	53.9	11.14	38	155000	155000
1991	79.01	55.34	12.56	29.5	160000	165000
1992	74.21	49.17	4.73	37.9	250000	250000
1993	71.95	49.87	12.56	36.6	287000	290000
1994	75.52	52.37	8.9	36	256000	260000
1995	78.97	54.09	7.07	28.1	190000	190000
Stutman County						
Jamestown Weather Station						
Date	Tmax	Tmin	Precip	Bu/Acre	Acres Har	Acres pla
1986	81.7	58.0	9.32	31.3	267000	270000
1987	83.4	59.0	7.24	31.3	279000	280000
1988	88.0	60.6	4.8	12.7	204000	280000
1989	83.2	55.8	7.83	21.4	329000	330000
1990	80.9	55.5	8.92	42.2	338000	340000
1991	82.46	57.29	6.29	33.2	330000	330000
1992	76.16	50.40	6.29	41.2	378000	380000
1993	73.37	54.93	20.8	30.9	349000	390000
1994	77.63	55.95	10.14	29.3	357000	370000
1995	80.87	58.89	13.89	28.1	340000	350000
Morton County						
Mandan Weather Station						
Date	Tmax	Tmin	Precip	Bu/Acre	Acres Har	Acres pla
1986	79.2	55.3	12.05	30.5	118000	130000
1987	80.1	56.0	10.5	28	121000	125000
1988	87.5	58.4	5.66	7.6	62000	125000
1989	82.9	55.3	3.28	15	124000	150000
1990	81.5	56.2	8.15	16	107000	150000
1991	83.16	58.00	5.56	22	122000	135000
1992	74.87	51.10	8.81	35.6	163000	165000
1993	73.98	52.67	19.79	28	171000	175000
1994	79.43	53.93	4.95	28.4	173000	180000

Central North Dakota Selected Counties Maximum Temperature, Precipitation, and Spring Wheat Yield. Sources: NOAA; USDA (NASS).

Western North Dakota						
Williams County						
Wildrose Weather Station						
Date	Tmax	Tmin	Precipitation	Bu/Acre	Acres Harvested	Acres planted
1986	77.8	51.9	6.49	31.4	190000	190000
1987	77.9	52.4	5.95	23.2	159500	160000
1988	84.5	55.0	5.15	7.5	140000	165000
1989	81.0	53.3	3.17	14	195000	200000
1990	78.8	52.3	7.62	21.5	182000	190000
1991	79.98	54.81	6.36	24.5	162000	165000
1992	74.34	47.91	4.88	37	210000	210000
1993	71.24	48.99	13.66	37.3	228000	230000
1994	77.22	51.00	6.89	32.8	199000	200000
1995	80.34	53.56	7.12	23.8	166000	170000
McKenzie County						
Keene 3 S						
Date	Tmax	Tmin	Precip	Bu/Acre	Acres Har	Acres pla
1986	82.90	51.23	5.3	27.5	90000	95000
1987	81.88	53.75	7.76	26	84500	58000
1988	89.36	57.61	3.78	9	72000	105000
1989	83.58	55.10	6.6	20.5	102500	115000
1990	82.41	52.74	8.55	30	93000	110000
1991	83.85	56.30	9.21	26	87500	100000
1992	77.24	49.17	7.61	40.9	129000	130000
1993	72.97	50.05	14.78	36.6	134000	135000
1994	79.75	52.26	8.2	36.4	129000	130000
1995	81.85	54.14	9.51	27.2	114000	115000
Golden Valley County						
Trotters						
Date	Tmax	Tmin	Precip	Bu/Acre	Acres Har	Acres pla
1986	80.9	53.9	7.77	23	48000	50000
1987	80.7	53.9	5.8	28	56500	57000
1988	89.7	58.2	1.41	6	22000	48000
1989	83.4	55.0	5.74	25	62800	65000
1990	83.1	54.1	5.52	24.5	63000	65000
1991	83.97	55.84	6.1	30	64500	65000
1992	75.92	49.84	6.89	37.8	79500	80000
1993	72.48	49.84	14.48	33.9	76500	80000
1994	80.87	52.62	6.67	28.3	79500	80000
1995	81.97	54.22	9.16	21.8	69000	70000

Western North Dakota Selected Counties Maximum Temperature, Precipitation, and Spring Wheat Yield. Sources: NOAA; USDA (NASS).

Detailed Descriptive Statistic

Mean is used to measure the average value of a selection of data. It is calculated by adding all the collected data values and dividing them by the number of participants. Median is defined as the middle point of a data distribution, and mode is defined the most frequently arising number. Standard deviation measures the variability or how much spread and dispersion from the mean value, and it shows the differences among the samples. A larger standard deviation demonstrates a greater variability from the average value. The variance of a data set is defined as the square of the deviation, which provides a measure of the average squared deviation of a set of values around the mean (McGrew, Jr., et al. 2014).

Nine Regions	Temperature Maximum (°F)								Temperature Maximum (°F)							
	1st Period: 1986-1990								2st Period: 1991-1995							
Weather Stations	Min	Max	Rang	Mean	Medi	Mode	Vari	Std.D	Min	Max	Rang	Mean	Medi	Mode	Vari	Std.D
Grand Forks	55	104	49	81.32	82	82	65.49	8.09	54	100	46	77.93	78	80	65.7	8.11
Fargo	56	106	50	82.6	83	82	69.72	8.35	55	100	45	78.82	79	79	59.84	7.74
Ashley	53	106	53	82.56	83	85	83.14	9.12	51	99	48	77.04	78	78	68.62	8.28
Bottineau	45	100	55	79.31	79	85	85.41	9.24	50	98	48	75.95	76	79	70.66	8.41
Jamestown	55	108	53	83.59	84	87	75.67	8.7	53	100	47	78.12	79	83	75.92	8.71
Mandan	54	105	51	82.28	82	80	90.23	9.5	51	103	52	78.47	79	77	82.37	9.08
Wildrose	52	104	52	80	80	78	95.49	9.77	45	98	53	76.65	77	79	89.85	9.48
Keene 3 S	55	106	51	84.16	85	89	83.85	9.16	46	101	55	79.13	79	80	86.44	9.3
Trotters	55	109	54	83.57	83	82	94.44	9.72	50	104	54	79.08	79	81	95.56	9.78

Nine Selected Weather Stations Maximum Temperature Descriptive Statistic for Two Periods. Source: NOAA.

Nine Regions	Precipitation (Inches) 1st Period: 1986-1990								Precipitation (inches) 2nd Period: 1991-1995							
Weather Stations	Min	Max	Rang	Mean	Sum	Mode	Vari	Std.D	Min	Max	Rang	Mean	Sum	Mode	Vari	Std.D
Grand Forks	0	2.45	2.45	0.08	37.17	0	0.05	0.23	0	4.44	4.44	0.13	61.01	0	0.15	0.39
Fargo	0	1.92	1.92	0.08	37.09	0	0.06	0.25	0	4.42	4.42	0.11	52.33	0	0.13	0.36
Ashley	0	2.7	2.7	0.08	37.93	0	0.07	0.27	0	3.06	3.06	0.12	56.64	0	0.12	0.34
Bottineau	0	2.94	2.94	0.09	42.96	0	0.08	0.28	0	1.62	1.62	0.1	45.82	0	0.049	0.22
Jamestown	0	1.93	1.93	0.08	38.38	0	0.05	0.21	0	6.35	6.35	0.12	57.41	0	0.18	0.42
Mandan	0	1.97	1.97	0.09	39.64	0	0.06	0.25	0	4.25	4.25	0.11	49.4	0	0.1	0.32
Wildrose	0	1.67	1.67	0.06	28.38	0	0.03	0.17	0	1.76	1.76	0.08	38.91	0	0.05	0.23
Keene 3 S	0	3.1	3.1	0.07	31.99	0	0.06	0.25	0	2.57	2.57	0.11	49.31	0	0.08	0.28
Trotters	0	2.51	2.51	0.06	26.24	0	0.05	0.21	0	2.94	2.94	0.09	43.3	0	0.07	0.27

Nine Selected Weather Stations Precipitation Descriptive Statistic for Two Periods. Source: NOAA.

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