American Journal of Climate Change, 2014, 3, 366-377
Published Online December 2014 in SciRes. http://www.scirp.org/journal/ajcc
http://dx.doi.org/10.4236/ajcc.2014.34032

Impact of Climate Variability on Yield of Spring Wheat in North Dakota

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Received 15 October 2014; revised 12 November 2014; accepted 2 December 2014

Abstract

Agricultural production is highly dependent on the climatic variability of the specific regions. Differential climatic and soil conditions bring about changes in yield, quality of crops thus affecting the economy. This study evaluated the impact of variability in different climatic factors keeping the other factors constant on spring wheat production in North Dakota from 2007 to 2011. The spring wheat yield mainly depends on the climatic changes during growing periods April to September. Average maximum air temperature was significantly different from April to September except June from 2007 to 2011. High average minimum and maximum air temperatures during planting time increase yield and planting area for 2010. In 2011, low mean soil temperature, excess rainfall in April caused low yield of spring wheat. The unmitigated climate variability will result in declines in yields. So, adoption of sustainable agriculture practices helps the farmers to develop the different practices for their farms.

Keywords

Climate Variability, Crop Production, North Dakota, Spring Wheat

1. Introduction

1.1. General

The impact of climate change and its changeability is a matter of concern in agriculture and is used to resolve food security issues. Climatic conditions all over the state are not same. It depends upon location to location. Crop production depends upon the climate and area. When climatic and soil conditions are normal or favorable for a crop, then there would be a high yield of crop with the best quality as well. If condition differs from normal,

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How to cite this paper: Bora, G.C., Bali, S. and Mistry, P. (2014) Impact of Climate Variability on Yield of Spring Wheat in North Dakota. *American Journal of Climate Change*, **3**, 366-377. http://dx.doi.org/10.4236/ajcc.2014.34032

then it affects the yield and quality of the products. Sometimes it causes damage of crop. Besides, most of the farmers are not aware about the suitable agriculture practices like sowing time, irrigation and fertilizer application scheduling etc. with reference to climatic and soils conditions. Crop diseases or pest infestation are also depend upon the local weather and planting time. The climate variability and the area where crop is grown are very important for the crop production. So, it automatically affects the economic condition of producers, consumers and government agencies. If crop yield is less, then price for those commodities is high for the consumers and overall affects the economy. So it is very important to grow the crop according to favorable conditions. It is important for the farmers to follow the instruction given by the research scientist and extension specialist like sowing date, irrigation application time and quantity, fertilizers application recommendations etc. because they work on the model and study the possibility of benefits and damage. Most of the farmers are not aware of different technologies, techniques and model study which help them in gaining economic benefits from the crops in different locations and also at different time.

Economic distribution in any country varies with the regions, crop and their environment. Yield of crop changes with grower's responses towards the crop like new varieties of the crop adoption, fertilizer and irrigation application changes, temperature and precipitation and are the major factors. Producers are more concern with the maximum benefits per acre. Cost of the product, quality, demand, procuring capacity is all depended upon the supply and the price changes. If prices are high then the consumer reduces their consumption or sometime stops it. So, it tends to less or no use of that commodity then comes to reduction in supply and overall affects the total welfare. So it is important to make the equilibrium between prices and quantities of the product. Product is from field by the grower and depends upon the climate and other factors for the production. Protect the crop from unavoidable changes from the climate from the longer term. At farms, the impact of climate change and its variability on crop production is calculated and helps the farmers to develop the different practices for their farms. It is used at a regional level at different spatial scales and determines the impact of climate change.

In North Dakota, blizzards, floods, droughts, tornadoes, hail storms, thunderstorms, high winds, severe cold spells, and extreme heat are common. Cyclical droughts with semi-arid conditions are common in the western half of the state. The eastern half receives most of the precipitation as rain in the spring and summer [1]. Agriculture is the largest industry in North Dakota, with wheat contributing the most to North Dakota's agricultural production [2]. The climate of the Northern Great Plains of North Dakota proved to be the best for spring wheat. It is planted from April to May and harvested from August to early September. The soil is considered the richest agricultural land in the world and ranges from thick black loam to more porous, sandy soil [3]. The rich black soil with high organic matter and the dry hot summer is ideal for the growth of wheat or other small grains. It is mostly grown in the Northern plains of the states. Local weather, soil condition, crop management and genetic information are used to predict the growth development and yield of the crop.

1.2. Objectives

The project evaluated the impact of variability in climatic factors on spring wheat production in North Dakota from 2007 to 2011. The objectives of the study are:

- Study the climate variability from 2007 to 2011.
- Change in spring wheat yield from last five year of data from 2007 to 2011.
- Study the impact of climate variability on spring wheat yield.

2. Literature of Review

The aim of climate variability impacts assessment is to increase the understanding of the regional and global effects of climate change on agriculture. Climatic factors include change in temperature, precipitation, and higher atmospheric CO_2 concentrations etc. Worldwide, scientists are working and modeling the effect of climate change on agriculture. This is very critical issue for society because people are fully dependent upon the climate for their survival.

Studies on the plant system and crop yield have shown that environmental factors like temperature and precipitation may play an important role either synergistically or antagonistically in yield determination [4]. It was also found that temperatures have impacts on yields and quality of many crops and increase in precipitation is useful in water shortage areas [5] [6]. The regions where the requirement of soil moisture is less and the moisture in soils is more create problems. If possibility of drought is increased then the demand for irrigation may also increase [7].

Change in climate is having less effect on total food production globally but the impact of climate change is more variable on a regional basis [8]. Developed countries are using new technologies and more adaptive adjustments are there but for some critically affected areas, production is affected. Agriculture is influenced by weather during growing season and soil of that area. The solution for increased crop productivity to predict the weather conditions ahead of time. So, better the knowledge of climate change the more efficient the response by agriculture. The scenarios for the grassland area showed that evaporation increases with increase in temperature and reduces the soil moisture accordingly. If evaporation goes for a longer time, then it can diminish the soil moisture content. So, an increase in temperature the prediction will extend the growing prairies season [9]. In the prairie region, agriculture production is affected by precipitation [10]. Climatic factors like soil moisture and temperature are sensitive to change agricultural areas of North America [11]. Daily and annual changes in temperature and precipitation, which lead to climate change, will impact the yield of the crop. The main crop yield in USA increasing at 1 - 2 percent every year constantly [12]. But there are some variations in some areas and in between time period because of climate variability, use of new technologies, different crops, agricultural practices, fertilizer use etc. From the last decade, it is assumed that agriculture of North America faces severe weather conditions from time to time. So to reduce this climate related risks, soil and water conservation and crop diversification are used [13].

USDA report on North Dakota spring wheat yield (**Figure 1**) shows the graph for yield versus year from 1990 to 2010. In 2011, yield was18 percent below the trends of yield and the harvested area shrank 13% due to serious planting delays and summer flooding. Spring wheat is planted in more marginal land due to its variability. Farmers use certified seed rather than saved seed out of their last grain harvest last year and also involve an application of fertilizer, seed treatments, and fungicide spray. Sometime it is a financial risk for the farmer, but also a greater return when crops grow well (National Agricultural Statistics Service, U.S. Department of Agriculture).

In North Dakota, climate plays an important role in wheat yield and production. **Figure 2** shows the weighted average wheat precipitation (mm) in North Dakota. It shows the precipitation for 2011 is much higher than the actual trend. Weekly crop reports from U.S. Department of Agriculture (USDA) mentioned increased incidence of disease from the wet and warm environment. Growers claimed that timely applications of fungicides were not always possible because of the extreme soil wetness.

North Dakota summer rainfall was the 8th wettest on record out of 116 years. Excessive rainfall spoiled the North Dakota spring wheat harvest, 48% above normal in the summer growing season. The June-August rainfall was 299.7 mm and 44% above normal (NOAA—National Oceanic and Atmospheric Administration). Crop production depends upon climate and area. When growing conditions are normal or favorable to crop, then there would be a bumper crop. If conditions differ from normal, then it affects the yield and quality of the products. It can cause damage to crop. The risk cannot be eliminated but can be minimized with contact to timely management

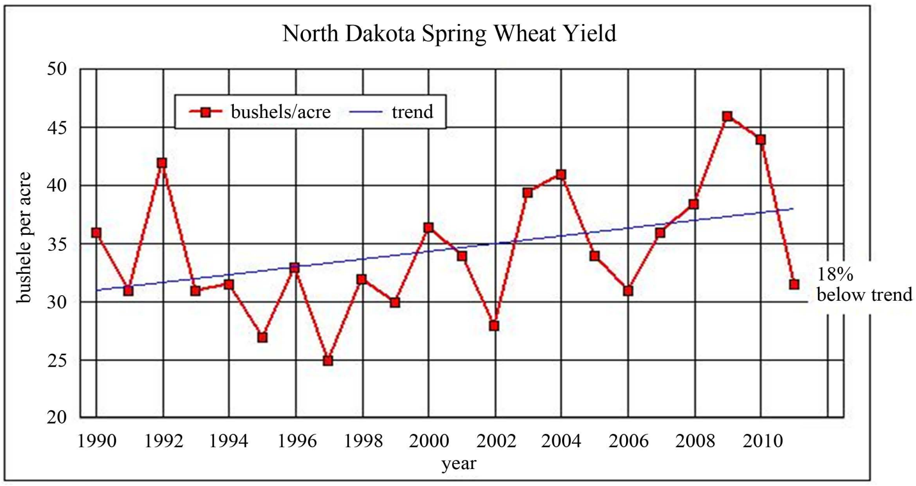

Figure 1. North Dakota spring wheat yield from 1990 to 2011 (Data source USDA).

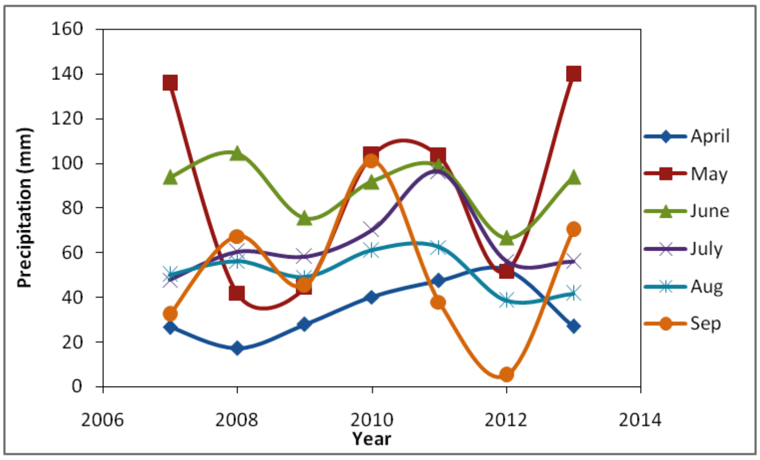

Figure 2. North Dakota's precipitation index in wheat growing season from the year 2007 to 2013.

that would permit farm managers to display crop condition to evaluate crop yields former to harvest. National Agricultural statistics service, USDA, North Dakota field office had made surveys completed by producers and dealers of the crops. This survey help the farmer in collecting past year information regarding crop, production, yield, area harvested etc. according to area wise.

3. Materials and Methods

3.1. Selection of Locations

Three location of North Dakota are selected for the study are Cavalier, Grand Fork, and McHenry randomly because these locations are very good for spring wheat growth and mostly grown in northern plains of the state.

3.2. Selection of Wheat Type

Hard red spring (HRS) wheat has selected in this study. Wheat (*Triticum* spp.) [14] is a cereal grain. Spring wheat does not require exposure to cold temperatures for normal growth and development. It can be planted in spring. Spring wheat is sown in the spring and harvested in early fall. Spring wheat is the staple food and is planted in April to May and harvested in August to early September. It is mostly grown in northern plains of the states. The productivity data in the three countries are given in **Tables 1-3**.

3.3. Weather Data

Climate data for last five year from 2007 to 2011 were collected for Cavalier, Grand Fork and McHenry in North Dakota. It is collected from sowing time (April) to harvesting time (September) for spring wheat. It includes monthly average maximum and minimum temperature, average soil temperature, total solar radiation, total PET (potential evapo-transpiration) and rainfall. The data for each year and county is presented in **Tables 4-18**.

3.4. Statistical Analysis

In the present study, data on yield was collected from the National Agricultural Statistics Service data (NASS, USDA) and climate data from NDAWN from 2007 to 2011. The tables of climate data from April to September for 5 years from 2007 to 2010 are attached in appendix. In this study, the statistical software SAS enterprise 4.3 was used for the analysis of the data and means separation was done using Fisher's least significance difference (LSD) at 95% Significance level. Fisher LSD test is used for the comparison of two or more means. This test can only be used when significant result is attained after the analysis of variance (ANOVA). The Fishers LSD test is basically a set of individual t tests. The formula for the least significant difference is:

$$\text{LSD} = t\sqrt{2\text{MSE}/n} \tag{1}$$

Table 1. Agriculture data for spring wheat in Cavalier county, North Dakota in 2007-2011.

Cavalier	Area planted (ha)	Area harvested (ha)	Yield (MT/ha)	Production (MT)
2007	135,575	130,313	2.845	370,816
2008	149,739	148,525	3.329	496,144
2009	121,410	116,554	3.127	364,964
2010	129,504	127,885	3.302	421,845
2011	123,434	123,029	2.811	345,641

Table 2. Agriculture data for spring wheat in Grand Fork county, North Dakota in 2007-2011.

Grand Fork	Area planted (ha)	Area harvested (ha)	Yield (MT/ha)	Production (MT)
2007	80,940	79,726	3.302	263,177
2008	78,917	78,512	3.800	297,469
2009	76,893	74,870	3.732	278,418
2010	77,298	76,488	3.786	289,848
2011	76,488	75,679	2.663	201,397

Table 3. Agriculture data for spring wheat in McHenry county, North Dakota in 2007-2011.

Mchenry	Area planted (ha)	Area harvested (ha)	Yield (MT/ha)	Production (MT)
2007	62,324	61,514	2.118	130,500
2008	66,776	65,561	2.286	150,095
2009	62,729	61,514	2.757	170,371
2010	69,204	68,394	2.690	183,979
2011	45,326	44,112	1.715	75,660

Table 4. Climate data for spring wheat in Cavalier county, North Dakota in 2007.

Month/Cavalier	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-07	11.3	−2.6	6.1	450	128.8	12.4
May-07	19.2	6.2	15.3	425	154.4	160.8
Jun-07	24.5	12.1	22.7	519	168.4	137.7
Jul-07	28.6	14.8	26.4	579	199.4	165.4
Aug-07	24.7	10.9	22.6	408	142.2	14.2
Sep-07	21.1	5.8	16.8	310	117.3	17.5

where:

t = critical value from the t-distribution table with a df (degree of freedom) from the denominator of the f statistic.

MSE = mean square error, obtained from the ANOVA test.

n = number of scores used to calculate the means.

In an attempt to improve the predictions, the coefficients of determination (R^2) were also computed in model summary which shows how well the data fits in the statistical model that is being used. The R^2 value ranges from 0 to 1 which then can be computed as percent to provide a better representation of the data. Higher R^2 gives better the prediction of dependent variables indicating better model to be used for future outcomes.

Table 5. Climate data for spring wheat in Grand Fork county, North Dakota in 2007.

Month/Grand Fork	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-07	11.2	−0.5	5.0	451	116.8	15.5
May-07	21.2	8.1	14.9	445	183.6	129.3
Jun-07	25.7	14.3	22.0	521	182.1	115.3
Jul-07	28.1	15.1	25.8	569	182.1	44.2
Aug-07	24.8	11.9	21.2	407	131.6	70.4
Sep-07	21.3	7.9	16.3	308	110.7	26.9

Table 6. Climate data for spring wheat in McHenry county, North Dakota in 2007.

Month/McHenry	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-07	11.2	−1.2	5.5	463	157.0	13.5
May-07	18.8	6.8	13.9	450	176.0	143.8
Jun-07	24.0	12.7	19.9	538	187.7	66.0
Jul-07	28.0	15.8	24.6	601	235.0	89.7
Aug-07	23.1	12.1	19.8	412	156.0	78.2
Sep-07	20.3	7.9	15.8	349	144.5	34.5

Table 7. Climate data for spring wheat in Cavalier county, North Dakota in 2008.

Month/Cavalier	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-08	10.6	−3.7	4.7	437	127.5	22.4
May-08	17.4	1.4	13.1	514	181.1	20.1
Jun-08	23.3	8.7	19.6	527	170.4	119.1
Jul-08	25.9	12.2	23.8	536	173.0	65.5
Aug-08	27.0	12.0	23.1	477	169.7	72.6
Sep-08	20.3	6.7	16.0	317	96.0	143.5

Table 8. Climate data for spring wheat in Grand Fork county, North Dakota in 2008.

Month/Grand Fork	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-08	10.8	−1.3	4.3	422	122.2	13.5
May-08	19.1	3.0	12.2	488	199.6	22.6
Jun-08	23.7	11.1	19.1	513	188.2	77.0
Jul-08	26.8	13.6	23.4	538	184.9	91.2
Aug-08	26.9	12.9	23.6	480	165.6	75.9
Sep-08	21.2	7.9	16.4	308	98.8	97.0

4. Results and Discussion

Climate is an essential component and varies from year to year. Crop productions are very much depends upon climate including temperature, precipitation change and other meteorological factors which varies through time.

Table 9. Climate data for spring wheat in McHenry county, North Dakota in 2008.

Month/McHenry	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-08	10.8	−2.3	4.5	466	165.4	5.8
May-08	17.2	3.3	12.0	519	210.3	12.4
Jun-08	21.6	10.4	17.4	540	199.6	125.5
Jul-08	25.8	14.3	22.7	576	217.4	66.5
Aug-08	26.1	14.2	21.8	500	206.8	71.4
Sep-08	19.8	7.9	15.2	340	127.3	124.7

Table 10. Climate data for spring wheat in Cavalier county, North Dakota in 2009.

Month/Cavalier	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-09	8.4	−1.7	2.9	366	87.6	35.1
May-09	16.8	2.0	12.2	483	156.2	94.2
Jun-09	23.2	9.3	20.2	513	163.1	92.7
Jul-09	25.0	10.8	24.0	574	185.7	36.1
Aug-09	25.1	11.4	21.3	420	135.9	46.7
Sep-09	25.0	10.6	19.9	375	127.5	90.9

Table 11. Climate data for spring wheat in Grand Fork county, North Dakota in 2009.

Month/Grand Fork	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Total rainfall
Apr-09	9.3	0.6	5.0	372	88.1	33.5
May-09	17.7	4.3	12.9	479	166.6	54.1
Jun-09	24.0	11.3	19.4	497	184.7	97.5
Jul-09	24.9	12.5	22.8	543	179.3	44.5
Aug-09	24.4	11.8	20.3	397	113.8	69.1
Sep-09	25.1	10.9	19.6	362	118.6	33.5

Table 12. Climate data for spring wheat in McHenry county, North Dakota in 2009.

Month/Mchenry	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-09	8.3	−1.0	3.2	418	107.2	45.0
May-09	17.0	3.9	10.7	538	194.6	48.8
Jun-09	22.1	10.3	18.4	529	193.5	29.5
Jul-09	24.1	12.3	21.8	584	228.1	32.5
Aug-09	24.3	12.8	19.8	434	167.4	81.8
Sep-09	23.8	11.6	18.3	395	149.1	112.8

In this study, the impact of climate on spring wheat was discussed and other factors remain constant.

The study was done on the basis of planting to harvesting for 2007 to 2011 for average of three counties.

Table 13. Climate data for spring wheat in Cavalier county, North Dakota in 2010.

Month/Cavalier	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-10	16.7	1.7	10.6	435	146.6	52.8
May-10	19.2	6.2	14.9	437	148.8	115.3
Jun-10	23.1	10.6	21.1	486	139.4	93.0
Jul-10	29.1	13.7	26.4	583	196.1	79.8
Aug-10	28.1	12.8	24.2	460	162.6	107.7
Sep-10	18.3	6.2	14.3	304	87.1	107.2

Table 14. Climate data for spring wheat in Cavalier county, North Dakota in 2010.

Month/Grand Fork	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-10	17.2	3.3	9.5	408	145.0	24.6
May-10	19.3	7.9	13.7	429	154.2	121.2
Jun-10	23.2	12.2	18.9	467	133.1	87.9
Jul-10	28.1	14.5	23.9	542	174.5	53.1
Aug-10	28.8	14.2	24.4	457	180.8	43.7
Sep-10	18.5	7.4	14.3	290	99.1	143.5

Table 15. Climate data for spring wheat in Cavalier county, North Dakota in 2010.

Month/Mchenry	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-10	15.5	3.2	8.1	434	166.4	35.6
May-10	17.6	6.8	12.1	459	179.1	77.7
Jun-10	22.4	12.3	18.9	534	175.5	116.3
Jul-10	26.5	14.7	23.3	577	211.3	53.1
Aug-10	26.6	14.1	22.7	492	195.6	43.7
Sep-10	17.7	7.4	13.7	320	116.6	110.2

Table 16. Climate data for spring wheat in Cavalier county, North Dakota in 2010.

Month/Cavalier	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-11	10.6	−1.3	4.6	372	86.4	49.5
May-11	17.1	4.6	13.1	418	132.6	88.6
Jun-11	23.4	10.2	20.7	486	152.7	106.9
Jul-11	29.4	13.6	26.4	555	183.6	71.9
Aug-11	29.0	12.7	25.0	485	173.0	19.1
Sep-11	22.7	6.7	17.2	373	124.5	103.6

4.1. Climatic Overview

The highest value for particular parameters like average air maximum temperature, average air minimum temperature, average soil temperature, total solar radiation, total PET and rainfall along with the year of observation

Table 17. Climate data for spring wheat in Grand Fork county, North Dakota in 2011.

Month/Grand Fork	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-11	10.1	0.8	5.0	377	85.9	72.6
May-11	17.3	6.1	11.7	408	135.6	75.4
Jun-11	23.4	12.9	17.6	468	166.9	73.4
Jul-11	27.9	15.7	22.4	538	177.0	93.0
Aug-11	26.7	13.4	21.7	460	156.7	55.6
Sep-11	22.0	6.7	16.7	369	123.7	31.2

Table 18. Climate data for spring wheat in McHenry county, North Dakota in 2011.

Month/Mchenry	Av. max temp	Av. min temp	Av. soil temp	Total solar radiation	Total PET	Rainfall
Apr-11	8.1	−1.3	3.2	407	96.5	35.8
May-11	15.8	5.3	10.5	427	154.4	40.6
Jun-11	21.8	11.9	17.7	494	165.9	150.4
Jul-11	26.6	16.1	23.5	556	200.9	142.0
Aug-11	25.3	14.3	21.9	493	183.1	98.6
Sep-11	20.4	7.9	16.2	389	147.1	56.1

during the study period is given in **Tables 19-25**. It also includes the coefficient of determination (R^2) value which helps us to indicate the quality prediction of dependent variable. Analysis shows that in most cases the average air maximum temperature, average minimum temperature, average soil temperature, total solar radiation, total PET and rainfall significantly different in each month from the year 2007 to 2011. However, there are some exceptions and data analysis revealed that there were no significance difference in June for average maximum temperature from 2007 to 2011 and June, August for average minimum temperature. The mean average soil temperature in May, July, August, and September for year 2007 to 2011 are not significantly different. In case of total solar radiation as well, there are months of May, June, August and September which did not show any significant difference. The mean total PET in April, June, August and September for 2007 to 2011 were not found significantly different. Similar observation is made for the mean rainfall in July for year 2011, 2007, 2008 and 2010 which are not all significant to each other.

4.2. Agricultural Overview

North Dakota's major industry is agriculture. Planting and yield progress for three counties (Cavalier, Grand Fork and McHenry) was taken as average from 2007 to 2011 (**Table 25**). There was a change in agricultural production from 2007 to 2011, which results from the changes in yields and changes in crop acreage. Changes in crop yields are due to the variability in climate and changes in acreage. The yield fluctuates due to the damage of some portion of sown crop because of the significant difference in planting and harvesting area.

From **Table 25**, it was shown that higher average planting area in 2008 was 98,477 hectare with yield 3.141 MT/ha and yield was higher in 2010 as 48.5 with average planting area as 92,002 hectare. It was shown that the harvested area in hectare is less than the area planted in hectare. Production in metric tons is depending upon Yield MT/ha) and area harvested. Area planted and harvested was increased from 2007 to 2008 followed by yield. Yield of 3.208 MT/ha from 87,011 hectare of planted area in 2009 and 3.282 MT/ha from 92,002 hectare in 2010 which was higher than 2007, 2008, and 2011.

There are number of factors which affect the decrease in planting area like high water table, climate, soil condition, variety of spring wheat, some agronomic factor, weeds, pest, and diseases etc.

In this study, climatic factors are used and other factors are keeping constant. The impact of climate variation on spring wheat yield in North Dakota depends on the actual patterns of climatic factors change during growing

Table 19. Average air maximum temperature.

Month	Highest maximum temperature (˚C)	Observed year	Coefficient of determination (%)
April	16.4	2010	95.15
May	19.7	2007	66.62
June	24.7	2007	45.59
July	28.2	2007	76.19
August	27.8	2010	71.55
September	24.6	2009	81.59

Table 20. Average air minimum temperature.

Month	Highest mean temperature (˚C)	Observed year	Coefficient of determination (%)
April	2.7	2010	78.17
May	7	2007	83.84
June	13	2007	56.96
July	15.3	2007	72.99
August	13.7	2010	59.88
September	11.1	2009	84.65

Table 21. Average soil temperature.

Month	Highest mean temperature (˚C)	Observed year	Coefficient of determination (%)
April	9.4	2010	88.5
May	14.7	2007	60.85
June	21.5	2007	47.75
July	25.6	2007	42.73
August	23.7	2010	58.75
September	19.3	2009	92.33

Table 22. Total solar radiation.

Month	Highest mean solar radiation (Lys)	Observed year	Coefficient of determination (%)
April	454.67	2007	75.87
May	507	2008	83.54
June	526.67	2008	53.8
July	583	2007	39.08
August	485.67	2007	86.96
September	377.33	2009	83.1

periods from April to September. Average minimum and maximum temperature can affect yield by accelerating the plant development and the functioning of the photosynthetic apparatus in 2010. Average maximum temperature was significantly different from April to September except June from 2007 to 2011. There was no significant difference in June and August for average minimum temperature. Temperature determines duration and timing of growing season for spring wheat.

Table 23. Total PET.

Month	Highest mean total PET (mm)	Observed year	Coefficient of determination (%)
April	152.7	2010	78.8
May	197.1	2008	66.73
June	186.2	2008	55.13
July	205.5	2007	10.37
August	180.6	2008	56.87
September	131.8	2011	49.19

Table 24. Rainfall.

Month	Maximum mean rainfall (mm)	Observed year	Coefficient of determination (%)
April	52.6	2011	72.38
May	144.5	2007	86.63
June	110.2	2011	20.8
July	102.4	2011	44.21
August	73.4	2011	6.91
September	121.7	2008	70.6

Table 25. Mean agriculture overview from 2007 to 2011 for Cavalier, Grand Fork, and McHenry in North Dakota.

Year	Area planted (ha)	Area harvested (ha)	Yield (MT/ha)	Production (MT)
2007	92,946	90,518	2.757	254,831
2008	98,477	97,533	3.141	314,570
2009	87,011	84,312	3.208	271,251
2010	92,002	90,923	3.262	298,558
2011	81,749	80,940	2.394	207,566

In 2007 and 2008, timely rains and moderate temperatures helped spring wheat to grow very well. A favorable weather condition increases the spring wheat planting area and it also increase the yield. In 2009, the planting days for spring wheat were dry across the State with snow in the northeast regions. The middle of the month had more rain showers across the State. In 2010, Warm, dry weather at the time of planting allowed producers to begin planting, temperatures and precipitation was above normal. Harvest was in progress and aided spring wheat development in end of August.

Crop establishment was a problem when soil temperatures are low. Plant emergence and its establishment for crop growth are affected. Yield was limited by amount of water received and stored in the soil during April 2011. In 2011, Temperatures was below normal during planting of spring wheat and precipitation was above normal. Freezing rain and snow added moisture to the already wet fields. Flooding remained a problem across the state. So, planting of spring wheat was pushed back again due to saturated fields and low soil temperatures. Late planting season and more acres were planted to other crop. Transpiration is a heat avoidance mechanism. A crop that maintains transpiration cooling may be a good heat avoider. The temperature of spring wheat standing in the field may be different from air temperature by some degrees. Transpiration rate is affected by these differences in air and soil temperature. Air temperature increases with increase in leaf temperature, when stoma of leaves closes due to water shortage. During planting time, solar radiation (385.33 Lys) and potential-evapotranspiration (89.7 mm) for 2011 was less. Solar radiation affects photosynthesis, transpiration, and also used to make plant biomass. Excess of rainfall in field affect the yield by flooding. There was also the stress prior to harvest of spring wheat in these locations.

5. Conclusions

Average minimum and maximum air temperatures affect yield of 2010 by accelerating the plant development and the functioning of the photosynthetic apparatus. Average maximum air temperature was significantly different from April to September except June from 2007 to 2011. There was no significant difference in June and August for average minimum air temperature. High average minimum and maximum air temperatures during planting time increase yield and planting area for 2010. In 2011, the mean average soil temperature was found low and represented low yield of spring wheat. During planting time, solar radiation and potential-evapotranspiration for 2011 was less *i.e*. 385.33 Lys and 89.7 mm respectively. This can affect the low yield because the amount of the dry matter of spring wheat produces is comparative to the amount of water that it transpires. In April, excess of rainfall in 2011 was 52.6 mm in field and caused flooding in the field. This gives in low yield.

The unmitigated climate variability will result in declines in yields. So, adoption of sustainable agriculture practices helps the farmers to develop the different practices for their farms.

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