IMPACT OF CLIMATIC PARAMETERS ON SPRING WHEAT YIELD IN NORTH DAKOTA

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MASTER OF SCIENCE

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ABSTRACT

The impacts of climate change in agriculture is a growing concern. The agricultural sector plays a significant role in North Dakota's (ND) economy, and spring wheat contributes most to the economy. This study focuses on assessing possible impacts of three climate variables on spring wheat yield in ND by building regression model. The trend of average minimum temperature, average maximum temperature, average precipitation and spring wheat yield was analyzed using Mann-Kendall test for 86 years. The study was conducted by dividing ND into 9 divisions. Increasing trend was noticed for 6 divisions for average minimum temperature and average precipitation during growing season. Northeast and Southeast division showed the strongest increasing trend for average minimum temperature and average precipitation, respectively. Eastcentral division had the most decreasing trend for average maximum temperature. Significant relationship was established between spring wheat yield and climatic parameters. The regression model was tested for forecasting accuracy.

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CHAPTER I. INTRODUCTION

1.1. Overview

The importance of climate change and its impacts in agricultural productivity is a growing concern these days. Studies on climate change impacts on agriculture have also been done in the past. However, real efforts have begun recently to address both direct and indirect climate change impact on the agricultural crops.

The agricultural sector plays a significant role in world's economy. There are several factors like fertilizer application, farming management practices, genetic composition of grains and other external factors affects the crop's yield highly. These factors are controllable and besides these, the climatic factors are also responsible for changes in the crop production. The climatic factors are at least roughly 32-39% responsible for the crop's yield globally (Ray et al., 2015). The yield may be different due to differential climatic condition based on the location. Climatic factors include precipitation, temperature, atmospheric humidity, solar radiation, wind velocity, atmospheric gases etc. Temperature, precipitation and solar radiation are the most important factors which influence the agricultural yield by affecting growth, development stages and productivity of crops (Nkeme and Ndaeyo, 2013).

Wheat is a major crop in the northern parts of US. Its botanical name is *Triticum* spp. (Belderok et al; 2000) and is a cereal grain that is used in the milling, baking and pasta industry all over the world. The consistent production of wheat is necessary to meet the food demand of the growing population. Mild summer with frequent rains are most favorable climate for growing of healthy wheat plants. Extreme heat and dry conditions has negative effects on wheat growth. The quality of wheat produced is also dependent upon the climatic conditions.

Agriculture is the leading industry of North Dakota (ND). Wheat is the number one crop in ND. The agricultural industry justifies for one fourth of the total economy of the state. According to the report by North Dakota Wheat Commission in 2007, the annual turnover of wheat to the increasing economy; the states average farm level wheat price in 2010 was $239 per ton ($6.50 per bushel), and the size of the crop was 9.9 million metric tons (362 million bushels) making the direct cash value $2.2 billion, which generates an additional $4.5 billion in indirect commercial activity. Besides wheat; corn, canola, flax, potatoes, barley, sugar beets, oats, soybeans and sunflowers are produced in large scale as well. ND ranked first in wheat production in the year 2009 and 2010 contributing as the leading wheat producer in the US. Three types of wheat is mainly grown in ND. They are spring wheat, durum wheat and winter wheat. In total the state accounts for about 30,300 farms, with an average of 1,300 acres (526 hectares) each. Approximately 19,200 ND farms grow wheat. Among the wheat farmers in ND, 74% grow spring, 25% raise durum, and 1% produce winter wheat. According to North Dakota Wheat Commission approximately 100 nations around the world have imported hard red spring and durum wheats from the state over the last five years. Wheat is produced in all the counties of ND. However, due to differential climatic condition the production rate varies. Favorable temperature, frequent rainfall, rich soil moisture, perfect amount of solar radiation are some of the major climatic factors that has impacts on the spring wheat yield of the state.

Spring wheat grows best in the climatic condition where summers are mild and not too hot for young plants. For this reason, ND, Montana, South Dakota and Minnesota are the biggest producers of spring wheat in US. Almost 90% of the ND's total land area which accounts for farms and ranches. The majority of those acres are planted in wheat (NASS, 2009).

In the past, the state has experienced significance losses of crops due to drought and increase in crops pests. This has occurred because of the differential weather condition affecting the economic sector of the state. The state has received some favorable years with very high yield of crops. If farmers are aware about the future impacts of climate change in agricultural sector, it is possible to implement strategies beforehand to avoid serious damage when the impact is negative. Similarly, advantages can be taken of the positive climate impact on agricultural production.

Climate change refers to the change in weather pattern which happens for longer period of time. It occurs mainly because of the amount of solar radiation received by the earth and also due to human activities. It brings about changes in the overall temperature, precipitation of the earth. The extreme cases of climate change include heavy rainfall, drought, desertification, flood, melting of ice caps and so on. From the ice age to present it is evident how the climate has changed over the decades. At present, the global warming has been an issue due to the climate change which is a result of increased amount of greenhouse gases in the atmosphere. Greenhouse gases traps infrared radiation or heat into the earth's atmosphere and prevents it from reflecting back towards space. The gases responsible for greenhouse effect are carbon di oxide, methane, nitrous oxide, chlorofluorocarbons and so on. The emission of greenhouse gases comes mainly from human activities e.g. the burning of fossil fuels, industry emission, oil and gas operation, household activities, agricultural activities and other kinds of energy uses.

According to the fourth assessment report by the IPCC (2007) there is going to increase in temperature across globe in the next century. The scientist in the IPCC also came to a conclusion that increase in global mean temperature of 1 to 3 °C above 1990 levels will have varying effect in different geographical location. Hence, a variation in the crop production in different regions is expected due to climate change. Some regions are expected to experience increased growth of different types of crops where other regions would show decline in yield. Consequently, contributing to the alteration of the world economy. Since, any effect in the agricultural production will directly impact the food demand worldwide for the growing population. Thus, it is important to study the possible impacts of climate change on agriculture and focus on adaptive measures to ensure long term food security.

1.2. Objective

The main goal of this study is to assess the possible impacts of three primary climate variables on the yield of spring wheat in ND. The specific objectives are:

To assess the changes and trends of average minimum temperature, average maximum temperature, average precipitation and spring wheat yield for the time period 1929-2014.

To predict the spring wheat yield by building a model.

To estimate the accuracy of the model for forecasting.

CHAPTER II. LITERATURE REVIEW

Climate change will have effects in almost every sector of our life including the agriculture. Varying temperature, rainfall pattern, altered soil moisture are some of the example of climate change. The impacts of climate change is going to vary across the globe in time and space. In some parts the impacts may be slow and extreme in others. Due to the impact, the vegetation of the earth will face variation in differential regions. Following the IPCC report (2007), the colder regions are expected to get warmer making favorable growth condition for new crop species to grow. In contrast, the warmer regions will get hotter which in turn is going to hamper with the optimal photosynthetic rate of the crop.

Wheat is one of the important commercial crop which is produced in more land area (more than 240 million ha) than any other crop (Curtis, 2002). Its production is dependent on the climatic condition as well as farming management, genetic changes also (McCaig and DePauw, 1995). Wheat yield can be measured by the presence of the number of productive tillers, the number of grains per spike, the number of spikes per square meter and the thousand grain mass (Giunta et al., 2003) Minimum temperature and maximum temperature is crucial for crop yield as slight changes have profound impact on the cell growth. Crops like cotton, corn and soybeans have shown higher yields up to a certain maximum critical temperature but beyond the optimum maximum temperature the yield decreases (Schlenker and Roberts, 2008). Past studies pointed out that increase in the minimum temperature is beneficial for wheat yield rather than increase in maximum temperature (Rosenzweig and Tuhiello, 1996). According to Briggle (1980), the optimum minimum and maximum growth temperatures of wheat is 3° to 4°C and 30° to 32°C, respectively. Nonetheless, the optimum minimum temperature varies based on the variety of the wheat. Emam

(2007) stated that average minimum temperature for germination is 0 ℃ and maximum temperature is 20-22 ℃. High temperatures negatively affect the growth stage of wheat by decreasing the mean photosynthetic rate and subsequently total biomass (Monson et al., 1992). Wheat is adapted to a broad range of moisture conditions starting with annual precipitation of average of between 375 and 875 mm or from 250 to 1750 mm (Leonard and Martin, 1963). However, too much rainfall can hinder the root growth of wheat.

Increasing temperature causes increased precipitation due to more evaporation of water from the Earth surface (Tabari et al., 2011). The projected precipitation change in future is very uncertain, but increase in rainfall along with warming is expected (O'Gorman and Schneider, 2009). The report by IPCC (2001) states that there is an increased precipitation rate in the mid and high latitude of Northern hemisphere compared to regions in Asia and Africa in the last century. Nonetheless, the projected impact shows that the effect of temperature is more on agricultural production rather than any other climatic factors responsible (Lobell and Burke, 2008).

The global warming also lead to varying degree of climate change across the US. As revealed by environmental protection agency (EPA) the Midwest region will experience hotter summers and milder winter, southeast will experience a rise in the sea level and also higher temperature will affect crop proactivity; same can be concluded for Northwest region and Southwest region. Droughts will be more frequent for Great Plains. The report also states that the Alaska has warmed twice compared to any other regions over the last 60 years. ND lies in the upper northern region of Great Plains facing towards Canada. The state's average temperature has increased faster than any other state in US. It is predicted that the days with over 100°F is going to be double in the Northern Plains by 2050 (Shafer et al, 2014). The temperature changes forecasted to occur mainly during the summer time, but the changes will be seen during winter time also.

As the southern part of the Great Plains become drier due to increased temperature. It is expected the agricultural land shift would occur towards the northern region with milder winter, and increased precipitation (Shafer et al, 2014). Warmer temperature and increased rainfall may turn out to be beneficial for crop growth and yield.

The predicted climate along with land use changes can affect the dynamics and availability of soil, water and land resources leading to food insecurity (Lobell et al., 2008). Warmer temperatures have the ability to alter the rates of photosynthesis and respiration which in turn alter the crop growth rates (Long, 1991). Studies suggest that the minimum temperature increased three times compared to the maximum temperature over the period of 1951-1990 (Karl et. al., 1991).

ND State also experiences extreme weather condition like high winds, droughts, floods, thunderstorms during growing season which can be concern for farmers. Droughts during the 2002 and 2006 costs heavily for the farmers in the state. The cost of the crops damages due to the 2002 and 2006 drought was about $223 and $425 million annually (Karetinkov et al., 2008).

The crop varieties of ND are also changed over the years. There are more varieties of crops found recently rather than found in the past. In the past the climate of the ND was not suitable for crops like corn to grow. However, due to change in climate the temperature of the state has increased. It added more days in the growing season of ND. The growing season has been increased by 1.2 days per decade from 1879 to 2008 which made crops like corn to grow (Badh and Akyuz, 2010).

Climate change is expected to bring changes in water resources, soil conditions, drought, desertification, flooding, disease, pest outbreaks and so on (Kurukulasuriya and Rosenthal, 2013). Rosenzweig and others (2002) assessed that the vulnerable areas will experience losses in agricultural productivity due to reduced crop yields.

The fourth assessment report by IPCC (2007) states that, even though the greenhouse gas concentration are stabilized, temperature rise of about 0.1 °C per decade is expected. It proves that the climate change is happening not for the sole reason of anthropogenic activities but also it is a natural course of climate to change over time. Nevertheless, the primary cause is the heightened greenhouse gas concentration in the air. Hence, the current and future emissions will be the key drivers of climate change. Rising temperature can cause changes in growing season length and planting dates of agricultural crops making the starting of the season warmer and the crops to reach maturity earlier (Porter, 2005). This may lead to alteration in the management of crops in variety of regions (Bootsma 1994). The evaluation of sixty years of data revealed seasonal temperature around the world is rising every year (NASA, 2011). Jarvis et al., (2010) assessed that beyond 1 °C of temperature increase, the overall impacts will be negative but the CO_2 fertilization may reduce the effects. Increased CO_2 concentration enhances the plant growth (Derner et al., 2003). The article also depicted that there are uncertainties involved while studying the impacts of the climate change on agriculture. As most of the climate change studies are based on models and models is unable to simulate all the factors those are responsible for climate change. Assumptions and missing data are also accountable for the uncertainties in the model study. Therefore, the model study can be referred to as just a prediction for the future and a possible outcome (Carter et al., 2001; Arnell et al., 2004).

Agricultural supply will be affected because of the climate change. Strong climate change impacts may directly or indirectly increase food prices or increase the value of land use. Thus, it would have effects on the relative prices of agricultural commodities. As a result, there will be reallocation of the resources within the agricultural sector, altering the structure of the economies of numerous countries and the international trade pattern (Deke et al., 2001).

Impact of climate change on agriculture has becoming a serious issue as the day passes. Hence, adaptations are necessary to minimize the risks of climate change impacts. Adaptation can be referred to the process or the practices that leads to being better suited to its surrounding environment without sustaining heavy damages. It is also an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities (IPCC 2001). As climate varies according to the geographical location, the impacts also varies. So, the adaptive measures will also be different location wise. Adaption measures can be implemented by individual farmers, community members, government agencies, international agencies and so on. Adaption often involves improved management practices in the agricultural farms and also, adaptation to progressive climate change (Vermeulen et al., 2013). The awareness for the changing climate and its probable impact on crops should be done at the farm level. Farmers should be instructed to follow the recommendation given by the research scientists and extension specialist like sowing date, irrigation application time and quantity, fertilizers application etc. because they work on the model and study the possibility of benefits and damage (Bora et al., 2014). With improved adaptive measures it is possible to minimize the extremities of food demand and also slower the pace of climate change to a certain extent.

CHAPTER III. METHODOLOGY

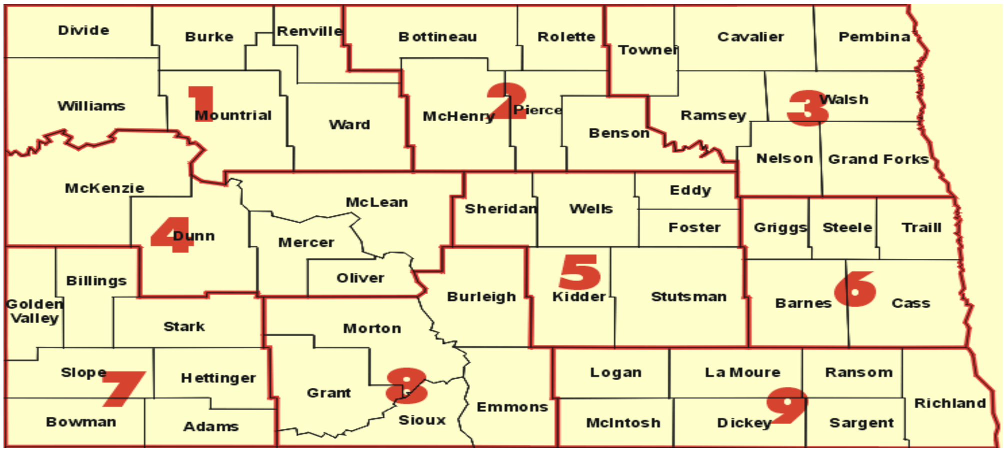
At first, the raw data are collected from websites maintained by U.S. Department of Agriculture and U.S. Department of Commerce. The data collected are then organized so that statistical analysis can be done. The statistical analysis involved finding out mean, standard deviation, range of data as a part of simple statistical analysis; then Mann-Kendall (MK) test, multiple regression analysis and finally cross-validating the regression model mainly.

3.1. Data Collection and Site Selection

The spring wheat yield data are collected from the website U.S. Department of Agriculture: National agricultural statistics service. In the data and statistics tab in the website the information can be acquired by states as well as the climatic division of US for the particular commodity.

Data for the 9 climatic division of ND on average precipitation, average minimum temperature and average maximum temperature collected from the primary website of National Oceanic and Atmospheric Administration (NOAA). The site comprises of National Environmental Satellite, data and Information Service (NESDIS) where in the National Climatic data center the weather data can be retrieved down in the division level starting from Nation wise. Eighty-six year's data were assessed starting from the year 1929 to 2014.

ND is divided into 9 divisions based on their climate. The 9 Climate Divisions of ND are namely Northwest, Northcentral, Northeast, West central, Central, East central, Southwest, Southcentral and Southeast region. Fig. 1 shows how the 9 climatic divisions are divided. The information on the different climatic division of ND is also been retrieved from the primary website of NOAA. It comprises of National Weather service: Climate Prediction Center where the climatic divisions according to the state or region have been sorted out.



Note:

Division 1- Northwest	Division 6- Eastcentral
Division 2- Northcentral	Division 7- Southwest
Division 3- Northeast	Division 8- Southcentral
Division 4- Westcentral	Division 9- Southeast
Division 5- Central	

Fig 1: Nine climate divisions of ND
(Source: National Oceanic and Atmospheric Administration)

Changes in average precipitation, minimum temperature and maximum temperature in the time period of 1929 to 2014 were evaluated. Only the growing season of spring wheat is taken into consideration which starts from April and ends in September. Growing season of spring wheat in ND starts from April and ends in September. April is the month when the planting of spring wheat starts. However, the temperature of April is very less and so the growth rate is low. The planting of wheat sometimes extends till May. June and July are the peak months where the growth of wheat occurs and the eventually comes to maturity. Spring wheat is harvested from mid-August to mid-September.

ND's climate can be illustrated with cold winters and hot summers. ND is situated in the upper Great Plain region closer to the upper Midwest region of US. It experiences some of the widest variety of weather. Division 3 and 6 are located on the eastern half side of the state which has humid warm to hot summers and cold, windy winters. Fargo is the largest city of ND which is situated in the east-central portion of the state surrounded by the Red River valley. Red river valley consists of red river which is a flat region and makes the surrounding regions fertile. The presence of the Red River influences the weather of that region including temperature and wind. Fargo is generalized with a continental climate meaning it has warm summers and cold winters with July being the warmest month of the year. The east central regions experiences highest precipitation or rainfall through month from May to August which are generally called the wettest month of the year. The presence of large devils lake which is the largest natural water body is present in the eastern side of ND also adds to the weather being humid in that region. Division 1, 4 and 7 are present in the western part of the state. The area has a semi-arid climate with less precipitation along with less humidity when compared to the eastern part. The west part comprises of mainly hilly areas. It appears that the areas east of the Missouri river get slightly colder winters, while those west of the stream get higher summer daytime temperatures. The central divisions are 2, 5 and 8. The central part of ND has almost the same temperature profiles like the eastern and western part. The central part contains Drift Prairie and the Missouri Plateau. Missouri plateau runs eastern side of the valley of the Missouri River. The Missouri River forms Lake Sakakawea in the central region of the state. Drift prairie region is characterized by rolling hills and shallow lakes. The south western part of the state consists of Great Plains or great American dessert including badlands. The eastern side of the state is closer to sea level and the topography level rises in the western part. The highest point in ND is White Butte Which is around 3,506 feet located near the southwest corner of the state in the Badlands area.

3.2. Basic Statistical Analysis

Basic statistical analysis was done for every division of ND to find out the mean, standard error of mean, standard deviation, minimum and maximum value of the variables. The mean indicates the average value of the data. Standard error of mean estimates variability between samples if there were multiple samples taken. Lower values of the standard error of the mean indicate more precise estimates of the population mean. Standard deviation refers to the amount of variation in the data within a single sample. Larger standard deviation results in larger standard error of mean. Minimum and maximum gives the highest and lowest value respectively.

3.3. Mann-Kendall Test

Trend detection of climatic parameters are important to see the changes through time series. It helps to assess the changes and be ready for the future. The changes of the specific climatic parameters are assessed using the Mann-Kendall (MK) test to observe the trends. The detection of trends in environmental studies is complicated by the overlaying of long and short-term trends, seasonal or weekly systematic variations, autocorrelations etc. The easiest way to assess trends in a data set is to plot linear trend line containing pairs of observations (Xi, Yi), so as to obtain the slope and intercept of a line that best fits the data. Still, this process has some limitations and assumptions. It is very sensitive to the presence of outliers in the data set. Sometimes it shows difficulties in handling data below the detection limit. That is why, linear trend line is not an effective method to study data from environmental studies. MK test is a statistical test that can be used to examine whether there is an upward or downward trend in data collected over a time period. The statistical software MINITAB version 17 is used to do the test.

MK test has been used previously in many climatologic and in hydrologic time series studies (Karmeshu, 2012). It is a non-parametric test. Therefore, data need not to be normally distributed. The test mainly finds out if the slope of the estimated linear regression line different from zero. In MK test, it takes X_1, X_2….., X_n be the set of data points observed at time T_1, T_2….., T_n, and let the corresponding MK statistics be S. For a pair (X_i, X_j), let the pair be positive, neutral or negative if (X_i, X_j) is greater than 0, equal to 0 and less than 0, respectively. Then S is the difference between the number of positive and the number of negative pairs. More precisely, let the set of positive and negative pairs be Np and N_m, respectively. Then,

$$N_p = \forall_{1 \le i < j \le n} \{(X_i, X_j), where\ X_i - X_j > 0\}$$
$$N_m = \forall_{1 \le i < j \le n} \{(X_i, X_j), where\ X_i - X_j < 0\}$$

$S = |N_p| - |N_m|$, where |Q| is the number of elements in set Q. (1)

In a MK test, the null hypothesis H_0 is that there is no trend in the data values. Thus the alternative hypothesis is that there is an increasing or decreasing trend. Intuitively, if S is a large positive or negative value, then one may expect an increasing or decreasing trend, respectively. To determine the trend statistically, we first compute the critical value (i.e., the point on the scale of the test statistic beyond which we reject the null hypothesis) and p-value (a function of test statistics, where the smaller the p-value value is, the more unlikely the null hypothesis). Both the critical value and p-value corresponding to a chosen significance level α and sample size n are queried from the Statistics database. If the test statistic is greater than the critical value and p-value is less than α, then we reject the null Hypothesis H_0 of having no trend in the data.

If the sample size of the interested data set is 10 or more, a normal approximation to the MK procedure is used. Then the test statistic Z_0 can be computed as follows:

$$Z_0 = \frac{S - \rho(S)}{\sqrt{\{V(S)\}}}, \tag{2}$$

$$where\ V(S) = \frac{1}{18}\ \ n(n-1)(2n+5) - \frac{1}{18}\sum_{j=1}^{g}\Big(\mathrm{t_j}\big(t_j - 1\,\big)\big(2\mathrm{t_j} + 5\big)\Big).$$

Here, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_j is the number of points in the jth group, and $\rho(S) = 1$ if $S > 0$, 0 if $S = 0$ and –1 if $S < 0$.

To determine the trend, we first compute the critical value $Z_{1-\alpha}$ and the p-value from the Statistics database that corresponds to the chosen significance level α. If $|Z_0| > Z_{1-\alpha}$, and p-value is less than α, then we reject the null Hypothesis H_0 of having no trend in the data.

3.4. Multiple Linear Regression

A linear regression analysis is performed to find a correlation between the climatic condition and the yield of spring wheat to find out whether the change in climatic condition changes the yield of spring wheat or not. The climatic divisions of ND is divided into two regions, east and west for carrying out regression. Division 2, 3, 5, 6 and 9 are considered as east region based on their elevation. Division 1, 4, 7 and 8 makes up the western part of the state for higher elevation compared to others.

Regression helps to predict the values of one variable which is dependent on the value of one or more values. The response or dependent variable *(Y)* relies on the changes of one or two predictor or independent variables *(X)*. The regression model uses the data to determine an equation to represent relationship between *X* and *Y*. Simple Linear regression uses one predictor variable whereas multiple uses two or more predictor variables and helps us to know whether a change in response variable is dependent on the changes in the predictor variables.

The Model can be expressed as:

$$\gamma = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k + \epsilon \qquad (3)$$

Where,

Y= is the dependent variable

X= is the independent variable

β_0 = is the intercept of the regression line that is the predicted value for y when x=0

β_1 ……β_k= is the slope or coefficients of the regression line – the marginal change in *Y* per unit change in *X* given that the other variables are constant

ε= refers to the random error, the error term is assumed to follow a normal distribution with a mean of zero and a constant variation. The regression equation is written as:

$$Y = \beta_0 + \beta_1 X_1 + \ldots + \beta_k X_k \qquad (4)$$

The ANOVA F−test is a test that all of the slopes in the model are equal to zero which is the null hypothesis (H_o). The alternative hypothesis (H_1) states that the slopes are not all equal to zero; i.e. at least one slope does not equal zero. This test is called the F−test for Overall Significance. The hypotheses statements appear as follows:

H_0: $\beta_1 = \ldots = \beta_k = 0$

H_1: At least one of β_i's is non zero

F statistic:

$$F = \frac{\text{Regression Mean Square (MSR)}}{\text{Mean Sqaure Error (M}} \qquad (5)$$

The p value is calculated at α=0.05 significance level. Lower p value than 0.05 indicates that there is sufficient evidence that a linear relationship exist between the variables based on the regression equation. The *Y* variable thus can be calculated following the regression equation. The regression analysis is done using the MINITAB 17 software package. Spring wheat yield is the response variable and the predictor variables are average minimum temperature, average maximum temperature and average precipitation.

While doing the regression analysis it also generates some important statistical output. The model summary which generates value for S, R^2, adjusted R^2 and predicted R^2 determines how well the model fits the data. S represents the standard deviation. It interprets that variation of data from the fitted value. The coefficient of determination, R^2, measures the amount of variation in the response variable *Y* that is explained by all of the predictor variables. Thus, checks the goodness of fit. The larger the R^2 the better the results. Adjusted R^2 takes the degrees of freedom into account. The larger the value of adjusted the better it explains the model. Predicted R^2 is helpful for determining the predictive ability of the model. Larger predicted R^2 represents better predictive ability for the model.

Residual plots and Normal probability plot is also significant while carrying out regression. Residual plots checks the goodness of fit for regression. The residual plot tells us whether the data is skewed or not. Likewise normal probability plot examines the assumptions for regression are satisfying. Normal probability plot tells us whether the data is normally distributed or not. The residual plots and normal probability plot is carried out using MINITAB software.

Often in regression analysis the presence of outliers can influence the outcome. Cook's Distance or Cook's D is able to measure the influence of those outliers and whether it has any effect on the slope of the regression line. The Cook's D were plotted using the statistical software

SAS. Data with large number of outliers and leverages is not fit for good regression model. It can be calculated as follows:

$$D_i = \frac{\sum_{j=1}^{n}\left(\hat{Y}_J - \widehat{Y_{J(\iota)}}\right)^2}{p\ MSE} \quad (6)$$

Where,

$\hat{Y}_J$ = the prediction from the full regression model for observation j;

$Y_{j(i)}$ = the prediction for observation j from a refitted regression model in which observation i has been omitted

p = the number of fitted parameters in the model;

MSE= the mean square error of the regression model.

3.5. Cross-Validation of the Regression Analysis

The regression model is helpful for finding out the impact of several climatic parameters on the spring wheat yield of ND. In addition, it can be also used to predict or forecasts the spring wheat yield for particular year. Thus, to ascertain the accuracy of the regression model cross validation is carried out. Cross-validation method is a validation technique which can be used to assess the results of regression analysis. It can be used to compare the results that is derived from the model with the observed results in reality. This technique helps to estimate the accuracy of the regression model for predicting the future spring wheat yield of ND. In this study, the data set is divided in two groups, few data points are selected from the whole dataset (training dataset or estimation data) which is used to predict few unknown data points against which the model is tested (testing dataset or prediction data). The goal of cross validation is to define a dataset to "test" the model in the training phase.

The drawbacks of taking few data points for estimation is that it would create larger variances of coefficients that is obtained from the whole dataset. It would also increase the standard errors of the estimated coefficients.

It is important to note that for better prediction, long time series and wide range of conditions are required. Normally, historical data especially environmental data is of lower quality in both accuracy and precision. As this study includes historical environmental data, it is expected that the prediction is not going to be 100% accurate.

After visualizing the data points of the whole dataset, it was established that there is an increase in the spring wheat yield more or less after ten years. Past studies also revealed that, average spring wheat yield shows considerable amount of increase in approximately ten years range, sometimes through an introduction of new variety and sometimes through introduction of new technology or farming methods (Smith, 1978; Gunderson et al., 2007). That is why, this study focused on taking ten years sample data from each division as estimation dataset while cross validating. Then to verify the regression model, the climatic data for the next consecutive years were put in the regression equation to generate the output for the spring wheat yield for all the division. The predicted spring wheat yield and observed yield are compared. Several data points are used to check the accuracy of the prediction. The actual yield and predicted yield is compared. Three sets of data were taken from the data set which act as estimation data which are from 1981-1990, 1991-2000 and 2001-2014 and they are used to forecasts the spring wheat yield of the years 1991-1994, 2001-2004 and 2010-2014 respectively.

The predicted yield is calculated using the regression equation that is generated. The difference of yield, percentage deviation of yield (error in predicting yield) and ratio of the yield is calculated as shown below.

Difference of yield= (Predicted spring wheat yield – Actual spring wheat yield)

Percentage (%) Deviation= (Difference of yield/ Predicted spring wheat yield) × 100

Ratio= Predicted spring wheat yield/Actual spring wheat yield

Box plots demonstrates the distribution of data and can help to identify outliers. In this study, the box plot shows the variation in the deviation of observed and predicted spring wheat yield for each year of prediction data and also for each division of ND. It represents graphically the summary of the following parameters; minimum, maximum. Median, 1st quartile and 3rd quartile of the data set. Box plot generated using MINITAB. Box plot with groups are performed. Years and division are used as the categorical variables for grouping.

CHAPTER IV. RESULTS

4.1. Total Spring Wheat Yield in Different Division

The unit by which the yield of a crop is measured is metric tons per hectare or bushels per acre. After harvesting of the grain, the total amounts of grains are weighed. The total number of bushels is divided by the number of acres harvested, and that is the "yield".

Figure 2 shows the average spring wheat yield in different divisions of ND for over 86 years of time. Division 3, 6 and 9 are the highest producers of spring wheat. Division 4, 7 and 8 are lowest producers.

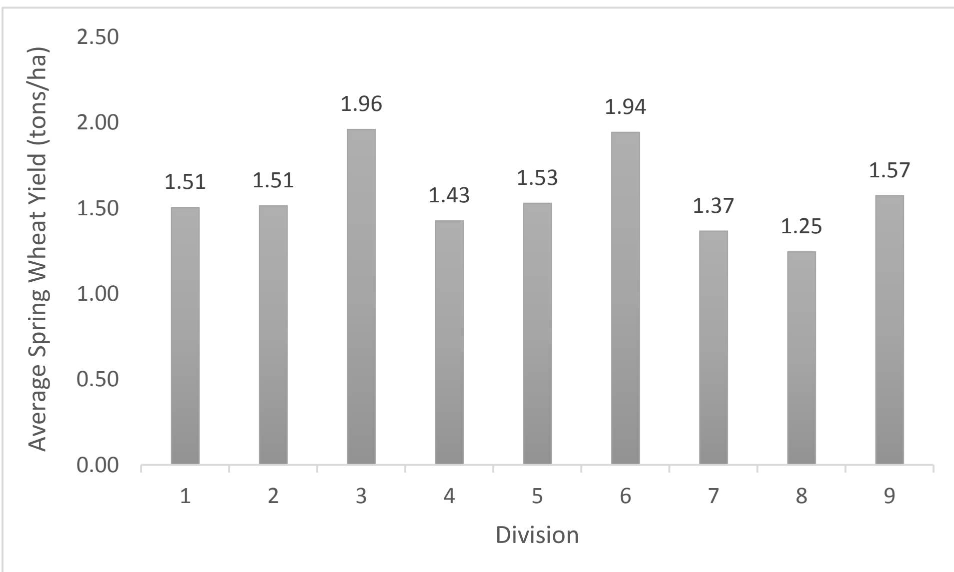


Fig 2: Average spring wheat yield in different divisions of ND

4.2. Basic Statistical Analysis

The basic/standard statistical analysis reveals the mean, standard error of the mean, standard deviation, minimum and maximum value of the data set. Table 1 shows the differences in descriptive statistics of the two regions, the east region and the west region of ND.

Table 1: Basic statistics of two regions of ND

Regions	Variable	Mean	SE Mean	Std. Dev	Minimum	Maximum
East	Wheat Yield	1.70	0.04	0.85	0.17	3.94
	Min Temp	7.81	0.05	0.95	5.13	10.11
	Max Temp	21.88	0.07	1.34	18.46	25.81
	Precipitation	60.91	0.70	14.31	21.38	105.79
West	Wheat Yield	1.39	0.04	0.67	0.13	3.00
	Min Temp	7.48	0.05	0.83	5.22	9.59
	Max Temp	22.36	0.07	1.35	18.82	25.95
	Precipitation	53.45	0.69	12.81	16.21	89.15

The mean spring wheat yield is 1.70 tons/ha and 1.39 tons/ha for the east and west regions respectively. The standard deviation, minimum and maximum value of spring wheat yield is higher for the eastern part. The standard error remains the same for both the regions.

The average minimum temperature has a mean of 7.81°C in the east which is slightly higher when compared to the west. The standard deviation is between 0.95 for the east and 0.83 for the west. The minimum value is lower for the east and maximum value is higher for the eastern part.

The mean value of average maximum temperature is 21.88 °C with a standard deviation of 1.34 for the eastern region. In contrast, the western region has a mean of 22.36 °C with a standard deviation of 1.35. The minimum and maximum value is greater in the west region by a small extent.

The mean of the average precipitation is 60.91 mm and 53.45 mm for the east and west respectively. The minimum and maximum value is higher for the eastern region.

4.3. Trends for Average Minimum Temperature Plot for Nine Divisions

Table 2 and Figure 3 shows the changes of average minimum temperature for a time period of 86 years from 1929 to 2014 in nine divisions of ND. The test statistic Z refers to the significance of the trend and also indicates whether the trend is strong or not. Here, the null hypothesis is tested at 95% confidence level or $\alpha=0.05$ for all the climatic parameters. The p value represents whether there is evidence to check the trends significance. If the p value is lower than the $\alpha=0.05$, then the null hypothesis is rejected. On the other hand, if the p value is greater than the $\alpha=0.05$, then the null hypothesis is accepted indicating that there is no trend found.

Table 2: MK trend test by normal approximation for average minimum temperature data of ND

Division	z-statistic	p-Value	A	Trend	Test Interpretation
1	1.72	0.04	0.05	Upward	Reject H_O
2	2.18	0.02	0.05	Upward	Reject H_O
3	3.02	0.001	0.05	Upward	Reject H_O
4	-0.21	0.42	0.05	No trend	Accept H_O
5	2.07	0.02	0.05	Upward	Reject H_O
6	2.97	0.002	0.05	Upward	Reject H_O
7	-0.71	0.24	0.05	No trend	Accept H_O
8	-0.18	0.43	0.05	No trend	Accept H_O
9	2.13	0.01	0.05	Upward	Reject H_O

Note: H_0 = There is no trend (Null hypothesis)
H_1=There is a trend either upward or downward (Alternative Hypothesis)

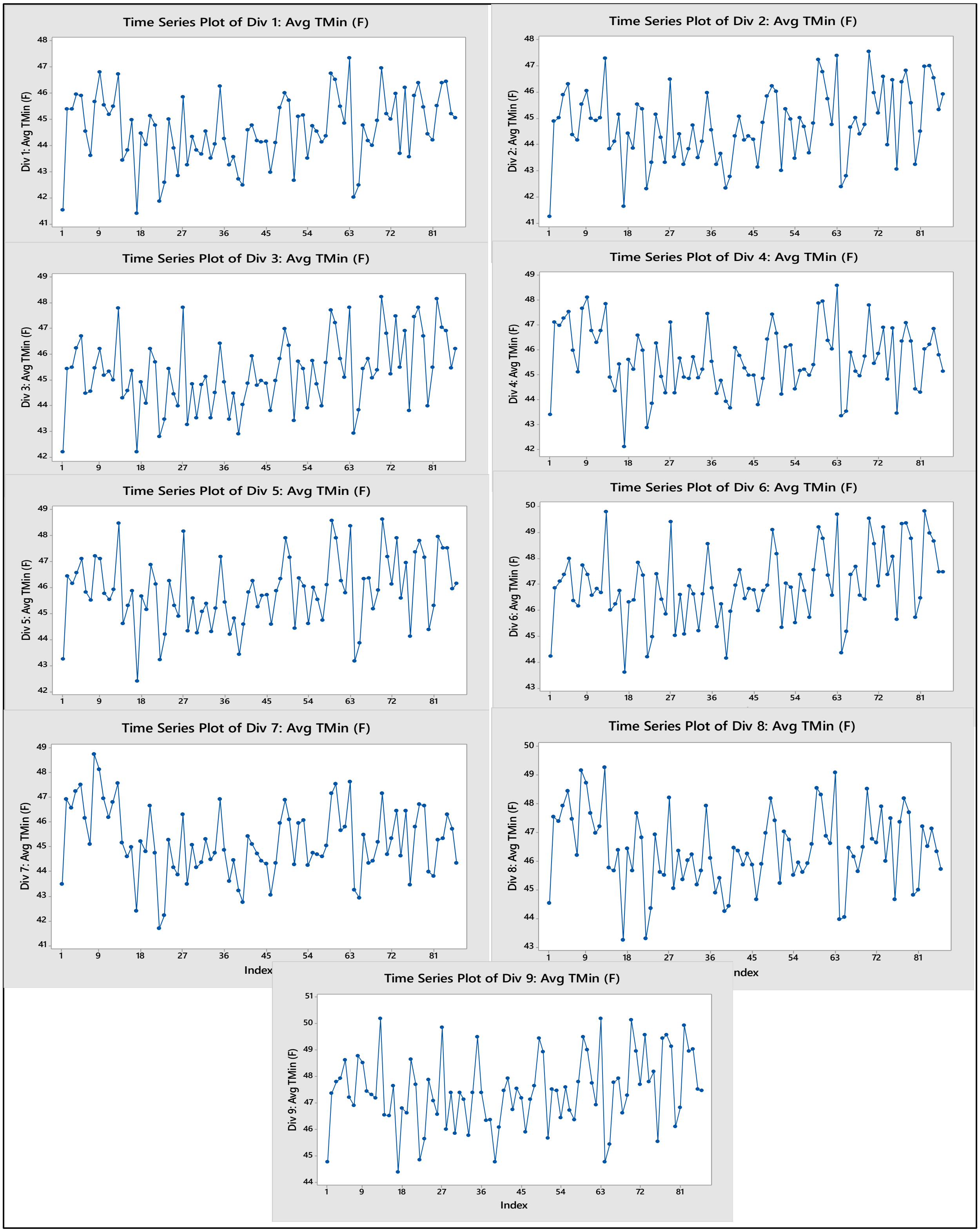


Fig 3: Time series plot for average minimum temperature of nine divisions of ND

The MK test for average minimum temperature reveals that division 4, 7 and 8 has no significant trend. This means that the null hypothesis is accepted and at α=0.05 significance level there is not enough evidence to determine that there is either a downward or an upward trend. Division 1, 2, 3, 5, 6 and 9 all showed an upward trend with p value lower than 0.05. The null hypothesis has been rejected in this case. Therefore, the alternative hypothesis has been accepted.

4.4. Trends for Average Maximum Temperature Plot for Nine Divisions

Table 3 and Figure 4 shows the changes of average maximum temperature for 86 years' time period from 1929 to 2014. The MK test for average maximum temperature data indicates a downward trend in the divisions 3, 5. 6, 8 and 9. Divisions 1, 2, 4 and 7 showed no trend. Thus, null hypothesis for case has been accepted with a higher p value.

Table 3: MK trend test by normal approximation for average maximum temperature data of ND

Division	z-statistic	p-Value	α	Trend	Test Interpretation
1	-0.34	0.37	0.05	No trend	Accept H_O
2	-1.32	0.09	0.05	No trend	Accept H_O
3	-1.65	0.04	0.05	Downward	Accept H_O
4	-0.06	0.47	0.05	No trend	Accept H_O
5	-1.73	0.04	0.05	Downward	Reject H_O
6	-1.72	0.04	0.05	Downward	Reject H_O
7	-0.75	0.23	0.05	No trend	Accept H_O
8	-1.85	0.03	0.05	Downward	Reject H_O
9	-2.11	0.02	0.05	Downward	Reject H_O

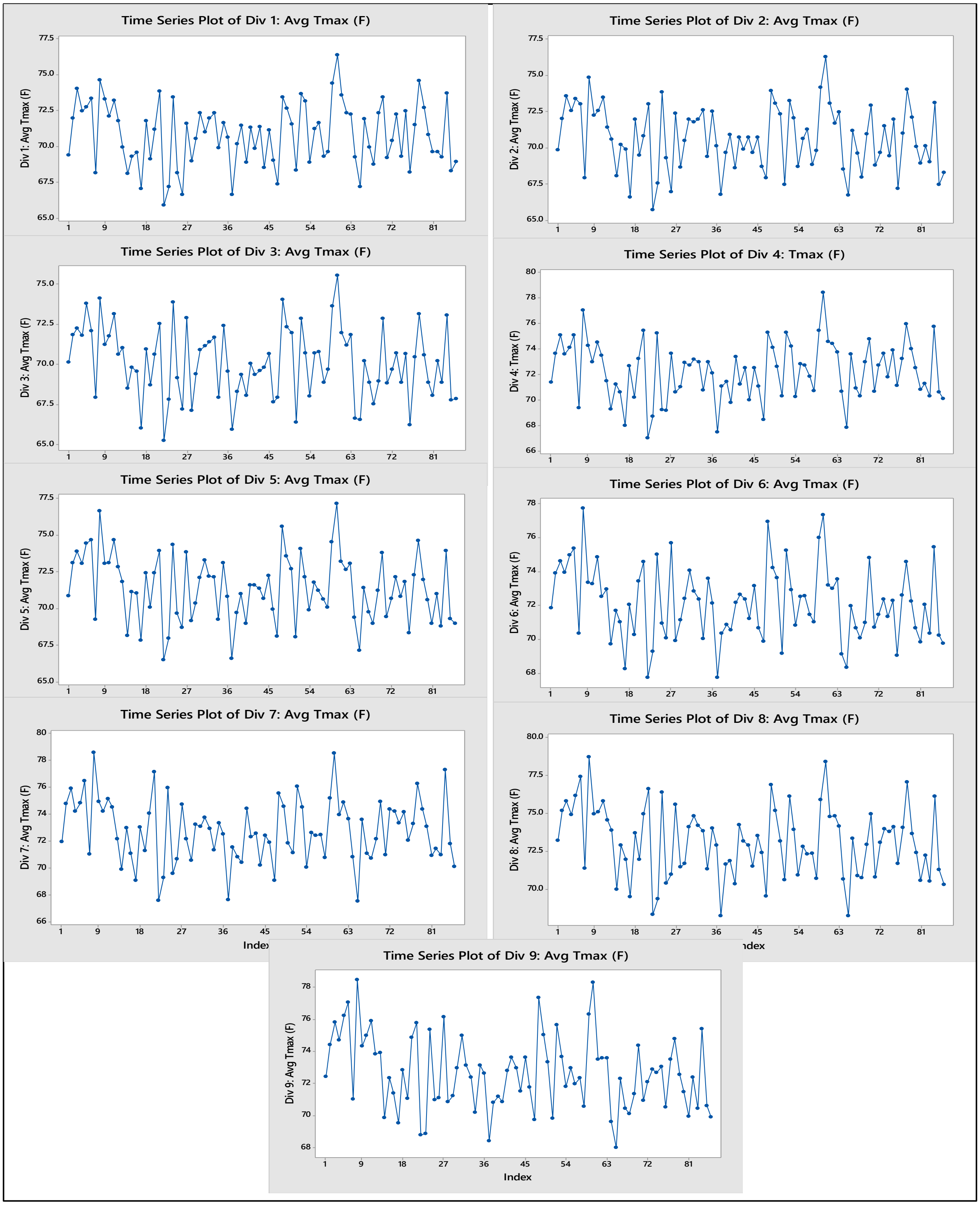


Fig 4: Time series plot for average maximum temperature of nine divisions of ND

4.5. Trends for Average Precipitation for Nine Divisions

Table 4 and Figure 5 show the changes of average precipitation for 86 years' time period from 1914 to 2014 in nine divisions of ND. Analysis of average precipitation of the nine divisions of ND for 86 years showed variable result. Divisions 1, 2, 3, 5, 6 and 9 showed significant upward trend. Divisions 4, 7 and 8 showed no significant trend. Divisions 3 and 6 have the highest MK test statistics.

Table 4: MK trend test by normal approximation for average precipitation data of ND

Division	z-statistic	p-Value	α	Trend	Test Interpretation
1	1.93	0.03	0.05	Upward	Reject H_O
2	2.14	0.02	0.05	Upward	Reject H_O
3	2.72	0.003	0.05	Upward	Reject H_O
4	1.25	0.12	0.05	No trend	Accept H_O
5	1.72	0.04	0.05	Upward	Reject H_O
6	2.91	0.002	0.05	Upward	Reject H_O
7	0.40	0.35	0.05	No trend	Accept H_O
8	1.17	0.12	0.05	No trend	Accept H_O
9	2.16	0.02	0.05	Upward	Reject H_O

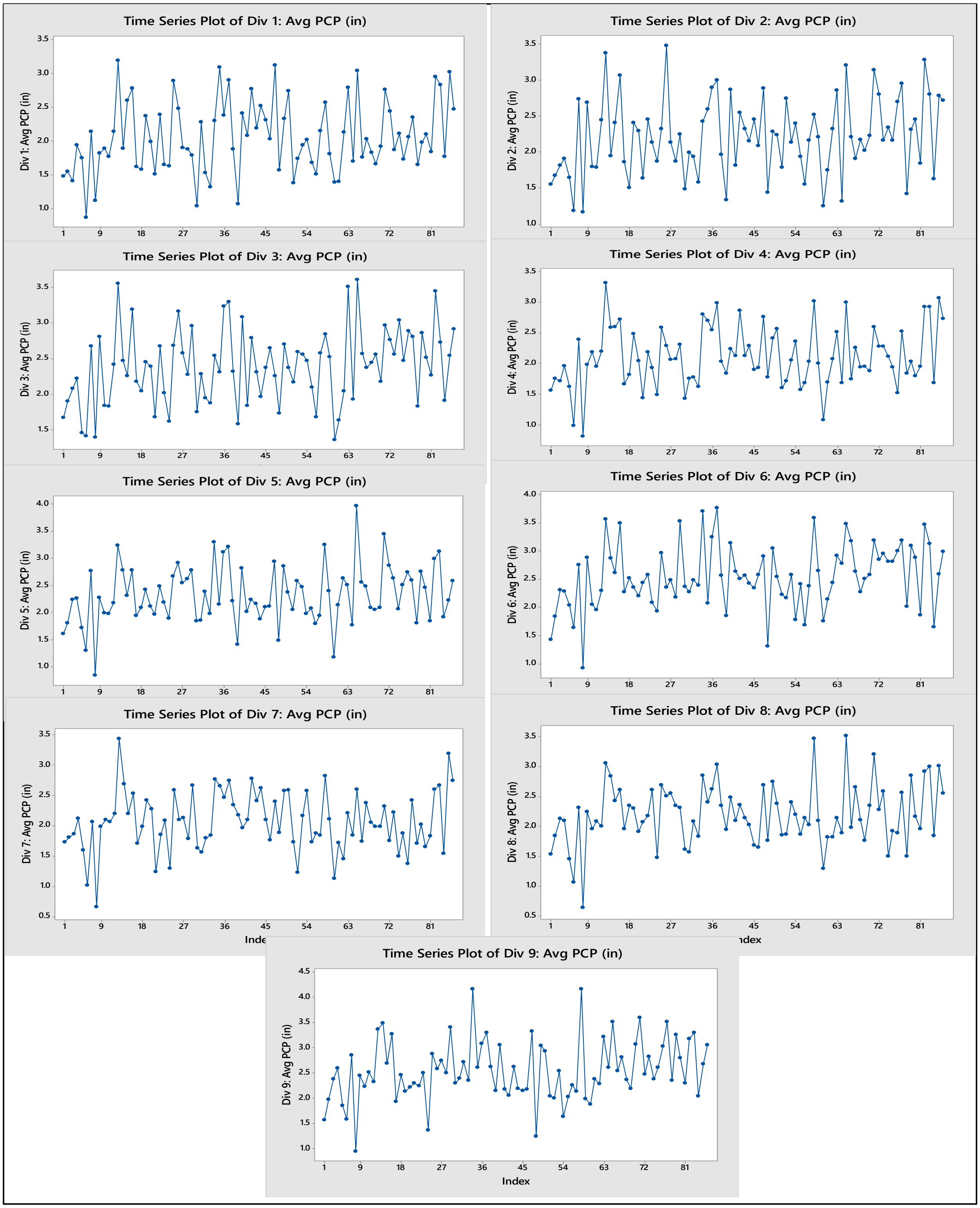


Fig 5: Time series plot for average precipitation of nine divisions of ND

4.6. Trends for Spring Wheat Yield of Nine Divisions

Table 5 and figure 6 represent the trend of spring wheat yield in different divisions of ND. The Mk test have increasing spring wheat yield trend for all the division of ND. Divisions 2, 3, 5, 6 and 9 have the higher value of test statistic. Division 4, 7 and 8 has the lower test statistics.

Table 5: MK trend test by normal approximation for spring wheat yield data of ND

Division	z-statistic	p-Value	α	Trend	Test Interpretation
1	9.00	0.00	0.05	Upward	Reject H_O
2	9.47	0.00	0.05	Upward	Reject H_O
3	9.94	0.00	0.05	Upward	Reject H_O
4	8.96	0.00	0.05	Upward	Reject H_O
5	9.60	0.00	0.05	Upward	Reject H_O
6	10.03	0.00	0.05	Upward	Reject H_O
7	8.13	0.00	0.05	Upward	Reject H_O
8	8.23	0.00	0.05	Upward	Reject H_O
9	10.20	0.00	0.05	Upward	Reject H_O

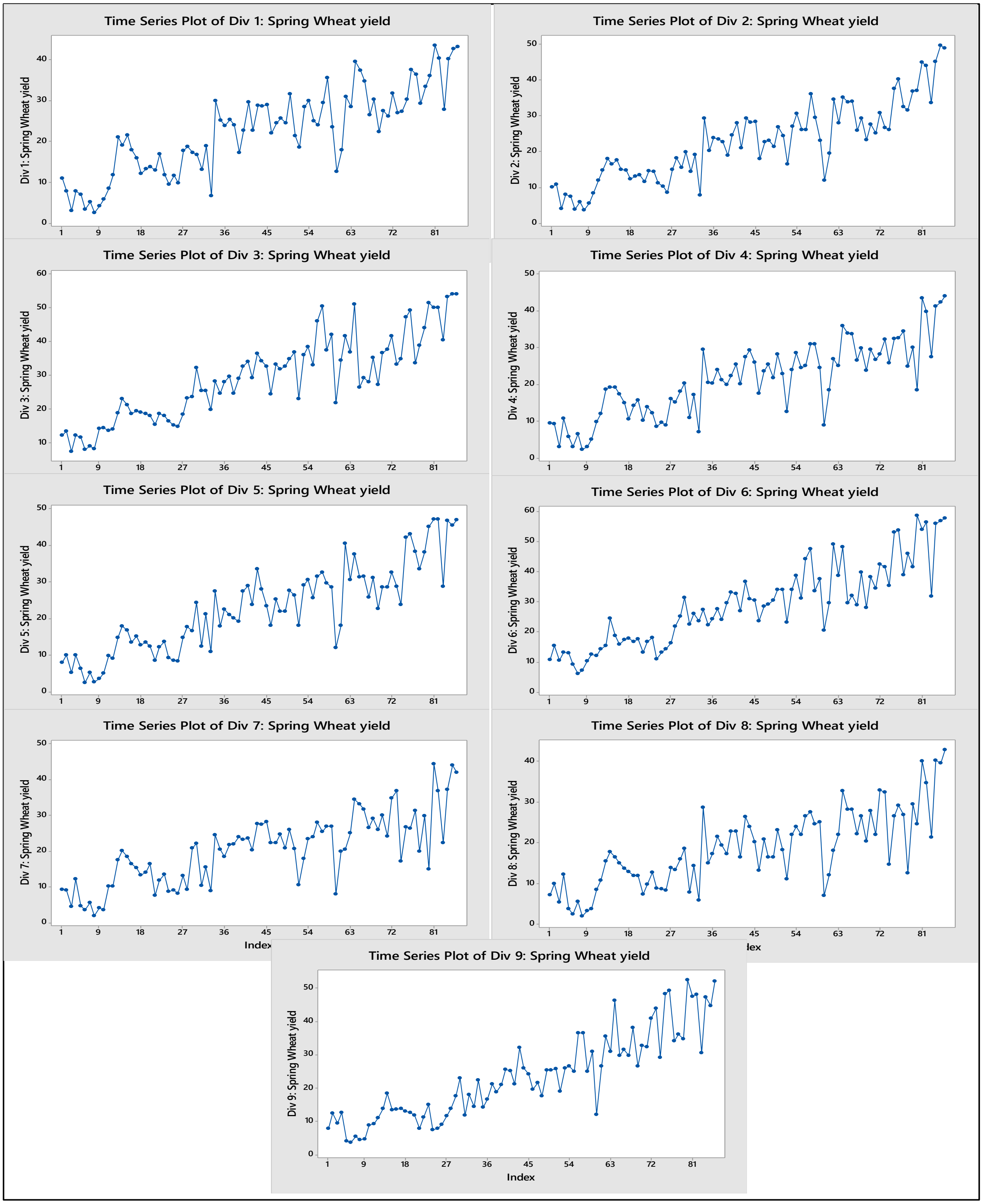


Fig 6: Time series plot for spring wheat yield of nine divisions of ND

4.7. Regression Analysis

Table 6 shows the regression equation of the two regions of ND that is generated from performing the multiple regression model. The regression equation explains how the unit changes in the predictor variables results in changes in the total predicted spring wheat yield.

Table 6: Multiple regression equation of different regions of ND

Regions	Regression Equation
East	Spring Wheat yield=8.266+0.6001Avg.Tmin-0.4845Avg.Tmax-0.01065Avg.PCP
West	Spring Wheat yield=0.966-0.1568Avg.Tmin+0.0208Avg.Tmax+0.02111Avg.PCP

Appendix A shows the results from the ANOVA table which are obtained from the regression analysis. It also shows the residual and normal probability plots for the entire division. The residual plots and the normal distribution plots follow a fairly random pattern and normal distribution curve respectively, indicating a good fit for a linear model.

The regression model as a whole was significant for both the regions as the p values were lower than $\alpha=0.05$ level for all the division. Analyzing each climatic variable of each division, the p value for some were found to be greater than 0.05 α level which indicates that the association is not statistically significant. The p value of ANOVA table indicates whether there is enough evidence at $\alpha=0.05$ significance level to conclude on whether there is a meaningful relationship between the variables. The type of relationship that exists between the variables can be known from the regression equation. A negative sign in continuous predictors indicates negative correlation and a positive sign indicates positive correlation. Positive relationship means that for every 1 unit increase of average minimum temperature and average precipitation the spring wheat yield will increase to some extent. Negative relationship is established between spring wheat yield and average precipitation. Negative relationship means that for 1 unit increase of average maximum temperature the spring wheat yield will decrease to some extent.

The regression model for the east region indicates a significant relationship of average minimum temperature, average maximum temperature and average precipitation with spring wheat yield as the p value is lower than the α 0.05. The regression equation reveals that the average minimum temperature is positively related with yield. On the other hand, average maximum temperature and average precipitation is negatively related with yield. The R^2 value suggests degree of variation explained by the model. R^2 value is approximately 23%. This can be interpreted as that the 23 percent of the variation in spring wheat yield are explained by average minimum temperature, average maximum temperature and average precipitation. Although, this leaves 77% of the data to be unexplained. R^2 value does not indicate whether the model is adequate. For the west region, the regression model is significant, p value lower for the model, and average precipitation. R^2 approximately 17%. The value for S (standard deviation) is 0.75 and 0.62 for the east and west region respectively. Lower S value indicates the model is adequate in describing response. Average precipitation is found to be positively related to yield in western part. The value of variance inflation or VIF is lower meaning there is no multicollinearity present in the data-set which is also good for carrying out regression. The VIF value larger than 5 or 10 is an indication that the associated coefficient is likely to be poorly estimated in the regression analysis. The VIF value is found to be lower than 5 for all the associated coefficients except for average maximum temperature which is 5.62.

Appendix B includes all the Cook's D plot spring wheat yield for all the division. Generally, the Cook's D value over point 1.0 is too much influential for the data set. In this case, there were none that reached that threshold value. Cook's D generally represents the potential outliers that can cause variance in the model. With more outliers present the model becomes invalid. Here in the study, the value for the year 1992 and 2012 were higher considering unusual than the others.

4.8. Cross Validation of Regression Analysis

Appendix C depicts the results obtained from the cross validation of data set. It includes tables (showing the percentage deviation or error from actual spring wheat yield), results from regression analysis of estimation data set, box plots of percentage deviation or error of different division in different years. For east region, the regression model is significant for two of the three sets. The percentage deviation is approximately around and below 30% in most of the cases. One or two data exceeded the error above 40%. According to box plots, the variation in percentage deviation is more for division 3 and 6 for the eastern part.

Cross validating the regression models for western region shows that, in certain years like 2012, 2002 and 1994 the percentage deviation yield is equal to or more than 50%. Other years show reasonably low percentage deviation of yield.

CHAPTER V. DISCUSSION

The trends of the nine divisions of ND were established from the MK trend test results. The test statistics were high for division 3, 6 and 9 in case of average minimum temperature. The test statistics for average minimum temperature are 3.02 and 2.97 for division 3 and 6, respectively. It is clear that, there was an increase in the average minimum temperature throughout time. On the other hand, for average maximum temperature division 5, 6, 8 and 9 showed higher test statistic meaning the presence of strong downward trend. Highest test statistics of 2.11 and 1.85 are reported for division 9 and 8 respectively. Therefore, the average maximum temperature of growing season has decreased. Furthermore, the spring wheat yield showed a strong upward trend for all the division which proves how the agriculture economy has boomed since the beginning of 1929. Division 9 and 6 possess the highest test statistics for spring wheat yield of around 10.

Maximum and minimum temperature are critical for the spring wheat growth. Like all the other crops spring wheat also has a limit for their optimal growth condition. Lower minimum temperature negatively affects the survival, cell division, photosynthesis, water transport, growth and finally yield of the wheat. Higher maximum temperature negatively affects mineral nutrition, shoot growth, pollen development and yield.

It is evident from the studies that the increasing trend of average minimum temperature and decreasing trend of average maximum temperature over 86 years of time in most of the division of ND can be potentially good for the spring wheat growth.

Also, with an increasing trend of temperature, it is likely the precipitation is also increasing. Precipitation in the growing season of spring wheat generally accounts for the total amount of rainfall. With an increased rainfall the wheat seedlings will have sufficient amount of water source and moisture content for their growth. Thus, an upward trend for average precipitation data in the growing season is actually beneficial for spring wheat production. However, too much rainfall can make the wheat yield to decrease by increasing the onset of disease or root problems (Curtis, 2002).

From the table 2, 3, 4, and 5 as well as the graphs 3, 4, 5 and 6; division 3, 5, 6 and 9 all showed a noticeable trend for all the parameters assessed. These divisions (Division 3, 5, 6 and 9) mostly comprise the eastern side of the state. Due to the presence of Red River, Devils Lake and the lowland experiences higher humidity compared to the western side. This explains the higher rate of precipitation in the eastern part. Humid weather ensures increased level of moisture in the air. The presence of moisture in the air is advantageous for the wheat seedlings. From the basic statistics analysis, it is found that the mean spring wheat yield is higher along with average minimum temperature and average precipitation. Mean value of average maximum temperature is lower. Thus, increased humidity, minimum temperature and decreased maximum temperature in the eastern part of ND is demonstrating favorable climate change for the spring wheat growth.

With the help of multiple regression analysis a meaningful relationship was established for the two regions of the state. It is notable that the eastern part experiences a humid weather in the summer due to its geographical location compared to the west. It becomes obvious the terrains are effecting the relationship. In contrast to the increasing trend of average precipitation and spring wheat yield, it is found from regression analysis that the average precipitation is negatively related to spring wheat yield in eastern region. This is can be explained by the fact that, excess precipitation in some years can cause hindrance in wheat growth. Pirttioja et al. (2015) reported that temperature has more impact on wheat growth rather than precipitation. Hence, the negative relationship of average precipitation with spring wheat yield (eastern region) that is established from the regression equation may also possess little effect on the yield in comparison with the positive effect of decreasing maximum temperature and increasing minimum temperature. On the contrary to the eastern region, the western region regression model indicates a significant positive relationship among average precipitation and spring wheat yield. As the mean precipitation is lower in the west, increasing trend of precipitation is advantageous for wheat produced there.

Cross validation of regression model provides an intriguing result. The error for predicting spring wheat yield is surprisingly less for certain years. However, years like 1994, 2003, 2004 and 2012 showed higher percentage deviation or error in forecasting. The higher percentage deviation closer to 100% for 2012 can be justified by the potential influential points as found in the Cook's D plot. 1994, 2003 and 2004's percentage deviation are around 50%. The rest of the years errors are 30% and below. Therefore, the model can be said to be moderately good for predicting spring wheat yield but not fully accurate.

The p value in the ANOVA table sometimes is very close to α=0.05 level, although it is lower. This happens because often the data from environmental studies does not follow a linear pattern. The data for climatic parameters shows a very subtle change rather than a drastic one. To quantify the exact and direct impact level of climatic variables on spring wheat yield is difficult and complex to do using statistical analysis. As the production of agricultural crops is not only affected by climatic condition sometimes it becomes impossible to assess the direct impact of climate change. Although, we assumed that the others factors responsible for spring wheat production are kept constant during the analysis. It is possible that some other statistical model will provide a different result on the impact level. However, from this study it is certain that there has been a change in the climatic variables assessed in the study for the past 86 years in ND and also that, the climatic variables has impact on the production of spring wheat in the region.

The impact that has been accomplished is mostly advantageous for the growth of spring wheat in the ND region especially on the eastern side. Thus, the farmers and researchers should use this advantage to increase the spring wheat production rate in the coming years.

CHAPTER VI. CONCLUSION

In this study, an upward or increasing trend has been found for average minimum temperature in six divisions, a downward or decreasing trend has been noted in five divisions for average maximum temperature. For average precipitation, an upward trend is found for six divisions among nine divisions in total. All the nine division showed strong upward trend for spring wheat yield. A significant relationship has been established using multiple linear regression. In addition, the accuracy of the regression model is found to moderately accurate. The changes in spring wheat growth and trends of climatic condition of the state gives us a comprehensive idea about the production rate of spring wheat in coming years. The changes in climatic variables is somewhat beneficial for spring wheat production of the region. Even so, there were years when the production declined compared to the previous due to extreme climatic events like drought. The model that is established is moderately good for predicting the future yields with the associated error. This study gives the base line information on the changes on climatic parameters and their relationship with the spring wheat yield. It has to be noted that the yield of spring wheat is not only affected by climatic factors rather non climatic factors also needs to be taken into account. However, following the changes of climatic condition, alteration and modification should be made in the farming practices, cropping system, cropping pattern, types of crop growing etc. Assessment of the impact of climate change on the spring wheat yield gave us the idea of how the farming management has also evolved over the past years corresponding with the slow climate change. The trend analysis of climatic parameters can help us to predict the future outcomes so that researchers can identify possible solutions in the fight against climate change or use the current conditions to their advantage.

Many factors such as global demand and supply, regional policies in the agricultural sector, and local infrastructure, along with geography of areas for agricultural production, simultaneously determine the climate change impacts. Analyzing climate change is complex. More scientific assessment on climate change is required in order to design policies that avoid unintended consequences. Based on the evaluation and estimation, different strategies can be implemented for the betterment of agriculture economy.

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APPENDIX A. MULTIPLE REGRESSION ANALYSIS

A.1. East Region-Regression Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	71.358	23.7859	42.52	0.000
Avg. Tmin (C)	1	40.626	40.6261	72.62	0.000
Avg. Tmax (C)	1	48.136	48.1361	86.05	0.000
Avg. PCP (mm)	1	4.422	4.4218	7.90	0.005
Error	426	238.306	0.5594		
Total	429	309.663			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.747932	23.04%	22.50%	21.65%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	8.266	0.909	9.09	0.000	
Avg. Tmin (C)	0.6001	0.0704	8.52	0.000	3.41
Avg. Tmax (C)	-0.4845	0.0522	-9.28	0.000	3.75
Avg. PCP (mm)	-0.01065	0.00379	-2.81	0.005	2.25

Regression Equation

Spring Wheat yield= 8.266 + 0.6001 Avg. Tmin-0.4845 Avg. Tmax-0.01065 Avg. PCP

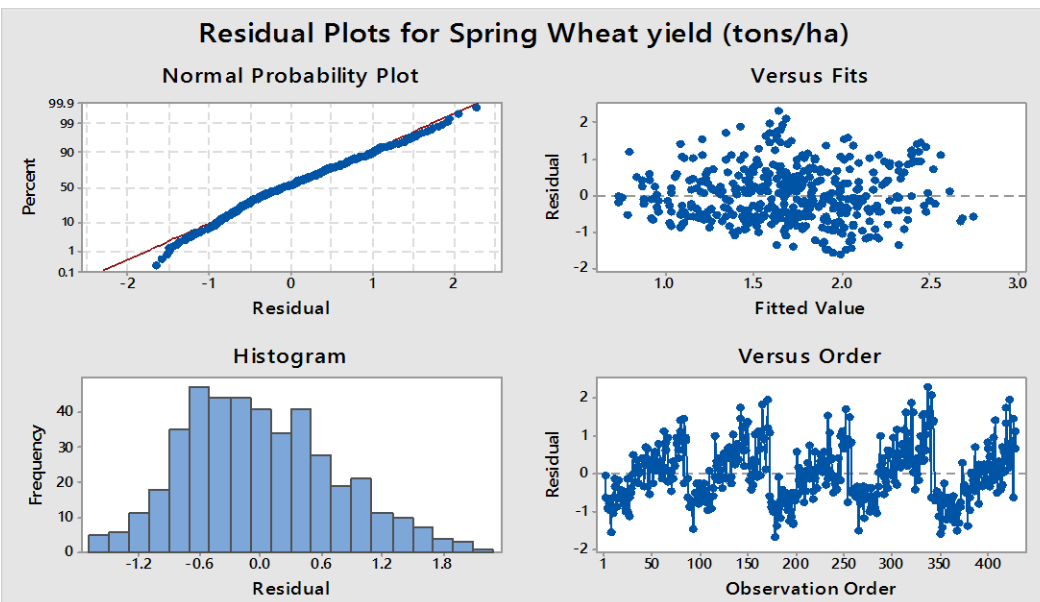

Fig A1: Residual and Normal probability plots of the east regions of ND

A.2. West Region-Regression Analysis

```
Analysis of Variance
Source              DF   Adj SS    Adj MS  F-Value  P-Value
Regression           3   26.248    8.7493    23.03    0.000
  Avg. Tmin (C)      1    1.375    1.3754     3.62    0.058
  Avg. Tmax (C)      1    0.048    0.0482     0.13    0.722
  Avg. PCP (mm)      1   10.129   10.1288    26.66    0.000
Error              340  129.186    0.3800
Total              343  155.434

Model Summary
       S    R-sq  R-sq(adj)  R-sq(pred)
0.616409  16.89%     16.15%      14.99%

Coefficients
Term                Coef  SE Coef  T-Value  P-Value   VIF
Constant           0.966    0.990     0.98    0.330
Avg. Tmin (C)    -0.1568   0.0824    -1.90    0.058  4.22
Avg. Tmax (C)     0.0208   0.0583     0.36    0.722  5.62
Avg. PCP (mm)    0.02111  0.00409     5.16    0.000  2.48

Regression Equation
Spring Wheat yield=0.966-0.1568 Avg. Tmin+ 0.0208 Avg. Tmax + 0.02111 Avg. PCP
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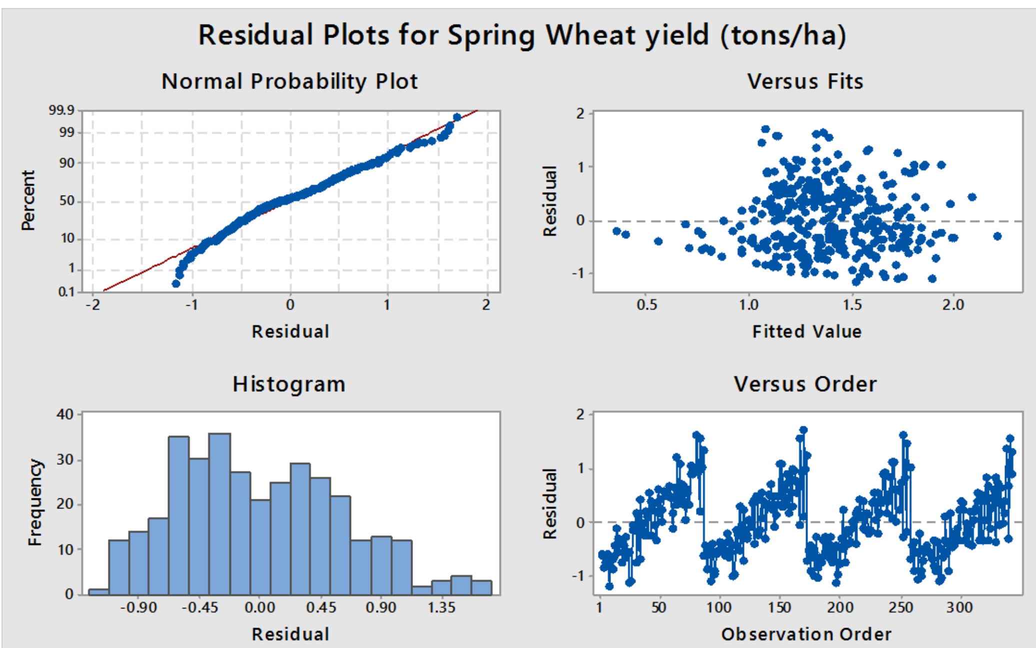

Fig A2: Residual and Normal Probability plots of the west regions of ND

APPENDIX B. COOK'S D FOR SPRING WHEAT YIELD

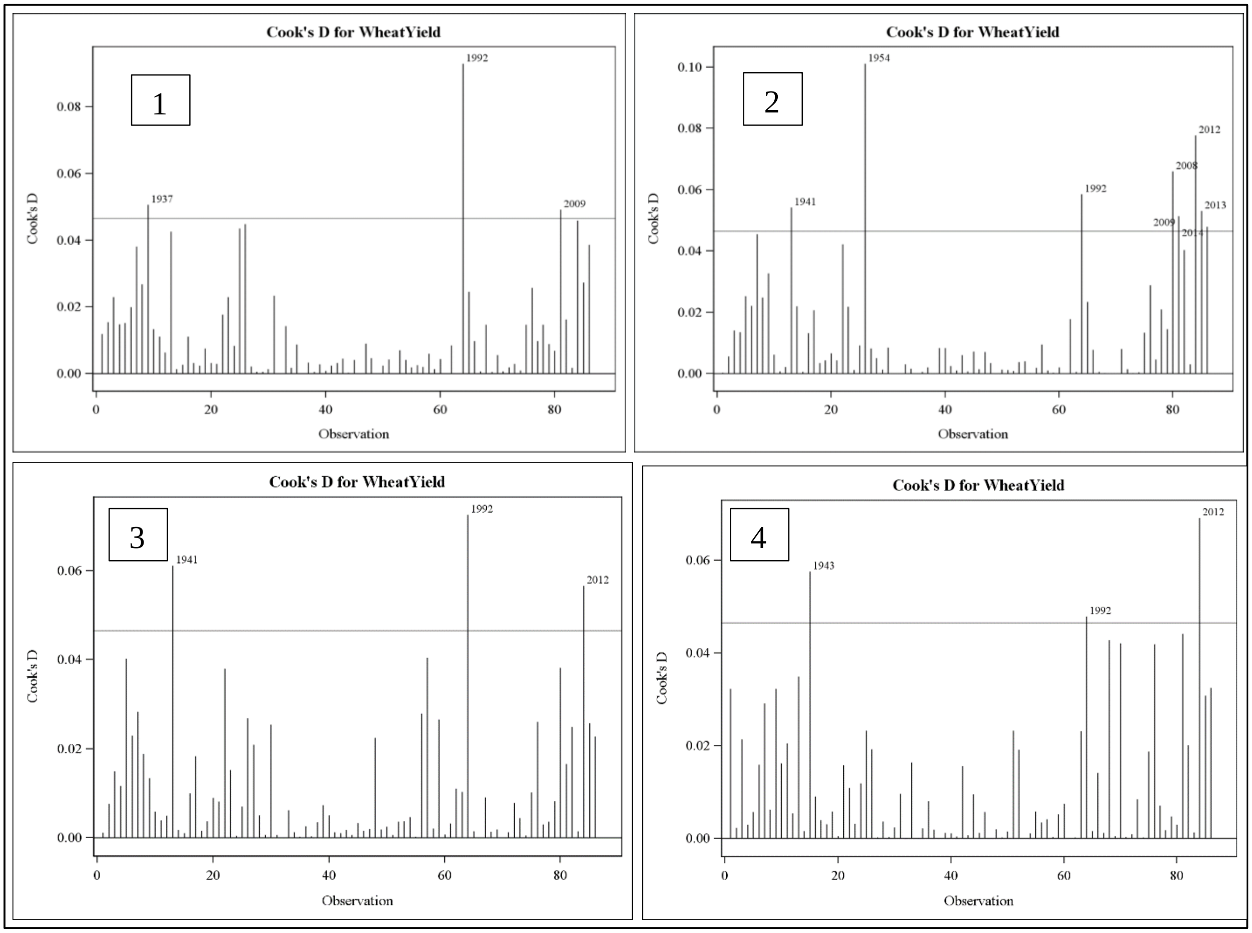

Fig B1: Cook's D of spring wheat yield for division 1, 2, 3 and 4 of ND

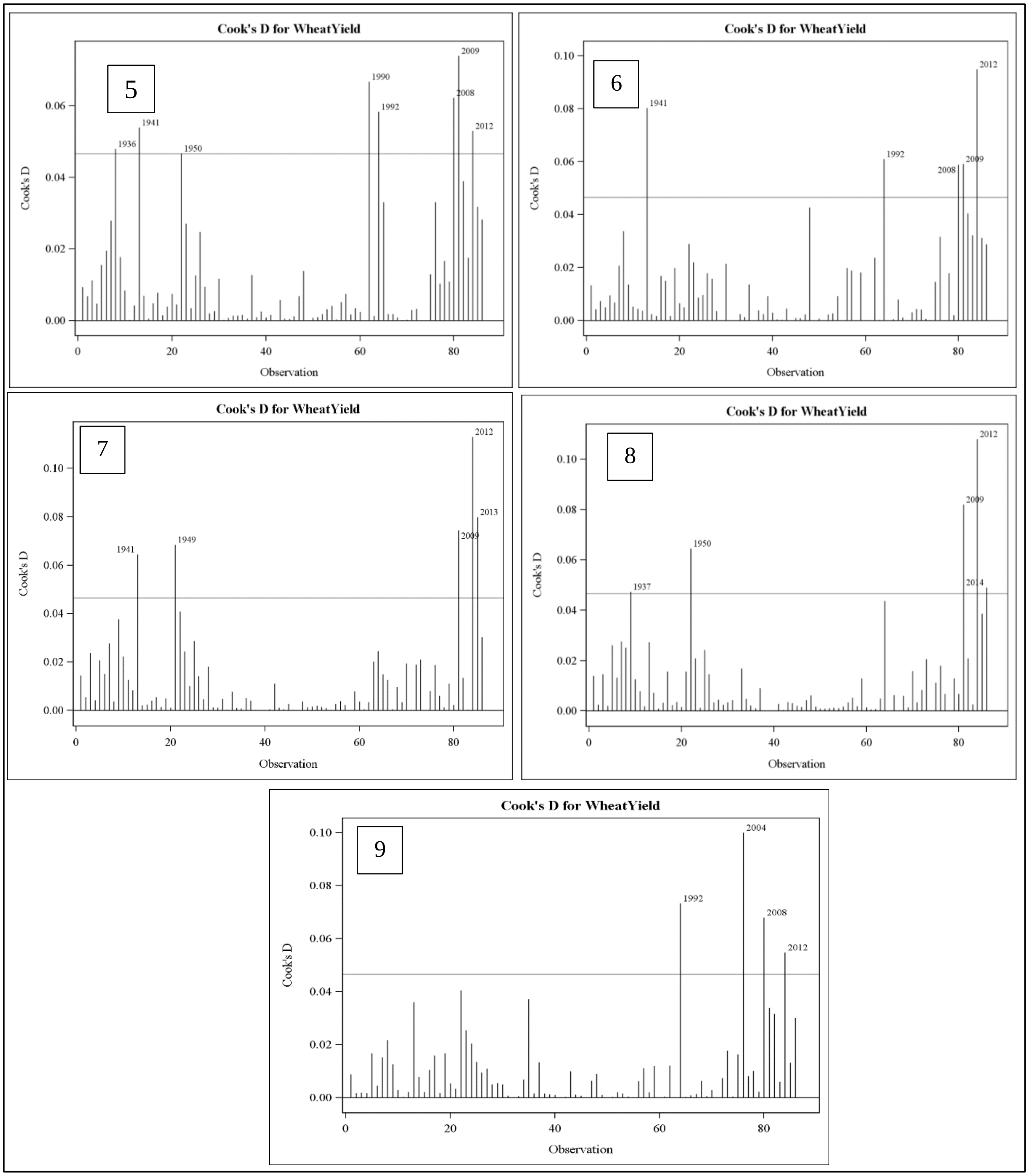

Fig B2: Cook's D of spring wheat yield for the division 5, 6, 7, 8 and 9 of ND

APPENDIX C. RESULTS OF CROSS VALIDATION

C.1. East Region: Cross Validation 1

Estimation dataset: 2001-2010

Prediction dataset: 2011-2014

Regression Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	2.6949	0.89830	3.15	0.034
Avg. Tmin (C)	1	0.6814	0.68141	2.39	0.129
Avg. Tmax (C)	1	1.5507	1.55073	5.43	0.024
Avg. PCP (mm)	1	0.0419	0.04193	0.15	0.703
Error	46	13.1298	0.28543		
Total	49	15.8247			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.534257	17.03%	11.62%	4.72%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	7.74	2.36	3.28	0.002	
Avg. Tmin (C)	0.229	0.148	1.55	0.129	3.94
Avg. Tmax (C)	-0.323	0.139	-2.33	0.024	3.60
Avg. PCP (mm)	0.00300	0.00782	0.38	0.703	1.58

Regression Equation

Spring Wheat yield= 7.74+0.229 Avg. Tmin-0.323 Avg. Tmax+ 0.00300 Avg. PCP

Table C1: Percentage deviation of yield of the east divisions of ND based on data from 2001-2010

Division	Year	Actual yield (tons/ha)	Predicted yield (tons/ha)	Difference (tons/ha)	Ratio	Deviation (%)
2	2011	2.26	3.21	0.95	1.42	29.65
	2012	3.04	2.33	-0.71	0.77	30.59
	2013	3.34	3.28	-0.06	0.98	1.83
	2014	3.28	3.20	-0.08	0.98	2.53
3	2011	2.73	3.25	0.52	1.19	16.08
	2012	3.59	2.41	-1.18	0.67	48.82
	2013	3.64	3.23	-0.41	0.89	12.77
	2014	3.65	3.34	-0.31	0.91	9.29
5	2011	1.93	3.35	1.41	1.73	42.28
	2012	3.14	2.34	-0.81	0.74	34.56
	2013	3.05	3.00	-0.05	0.98	1.79
	2014	3.16	3.10	-0.05	0.98	1.66
6	2011	2.13	3.25	1.12	1.53	34.43
	2012	3.76	2.19	-1.56	0.58	71.25
	2013	3.82	3.04	-0.77	0.80	25.35
	2014	3.88	3.16	-0.72	0.82	22.63
9	2011	2.05	3.25	1.20	1.58	36.90
	2012	3.18	2.28	-0.91	0.72	39.81
	2013	3.00	2.99	-0.01	1.00	0.23
	2014	3.51	3.14	-0.36	0.90	11.54

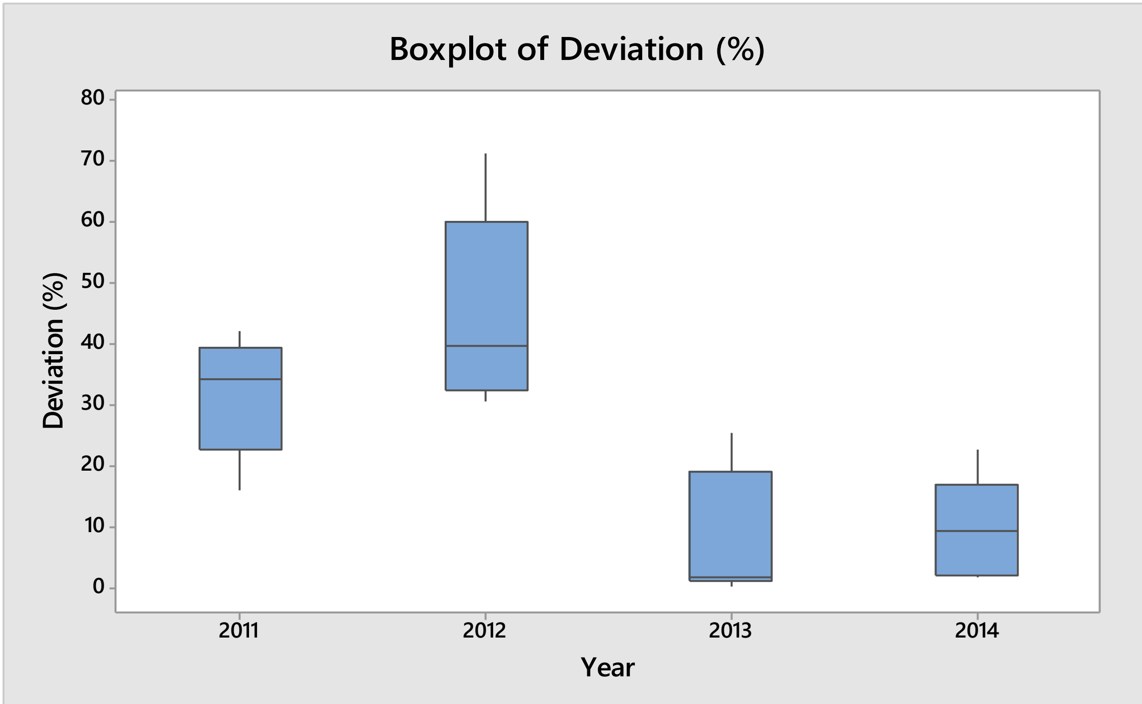

Fig C1: Box plot showing percentage deviation of yield from 2011-2014

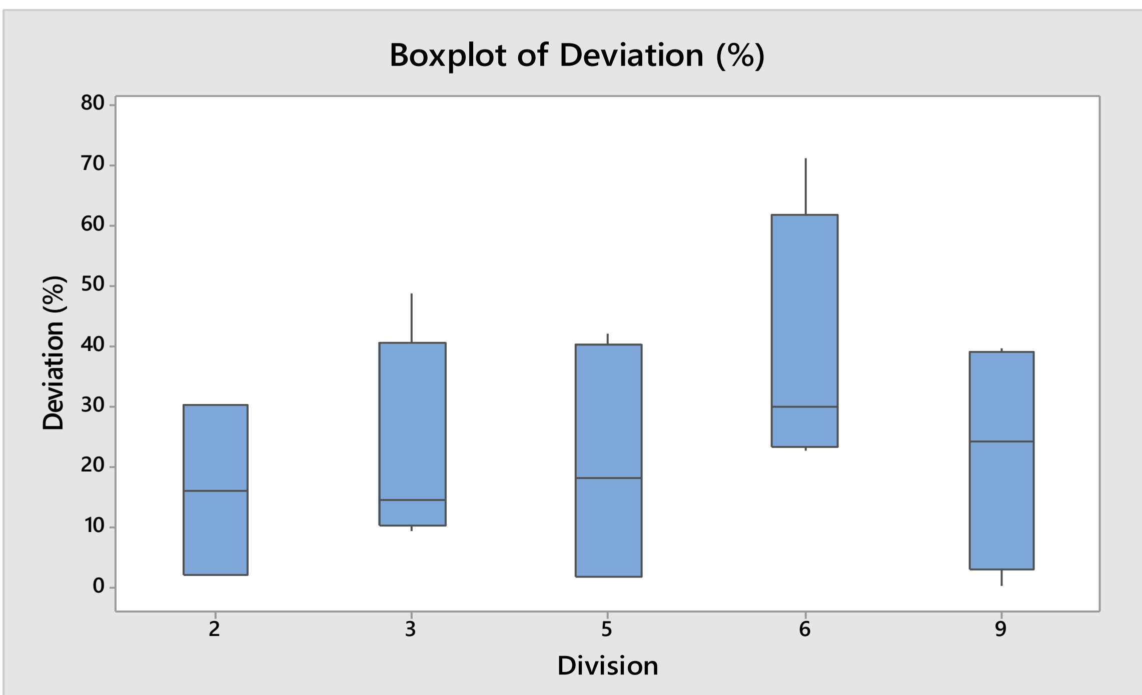

Fig C2: Box plot showing percentage deviation of yield in different divisions of ND

C.2. East Region: Cross Validation 2

Estimation dataset: 1992-2000

Prediction dataset: 2001-2004

Regression Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.10088	0.033627	0.18	0.909
Avg. Tmin (C)	1	0.03985	0.039850	0.21	0.645
Avg. Tmax (C)	1	0.00939	0.009391	0.05	0.823
Avg. PCP (mm)	1	0.00068	0.000683	0.00	0.952
Error	46	8.54445	0.185749		
Total	49	8.64533			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.430986	1.17%	0.00%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.14	1.92	1.12	0.270	
Avg. Tmin (C)	-0.061	0.132	-0.46	0.645	5.25
Avg. Tmax (C)	0.027	0.120	0.22	0.823	4.97
Avg. PCP (mm)	-0.00034	0.00557	-0.06	0.952	1.61

Regression Equation

Spring Wheat yield=2.14-0.061 Avg. Tmin+0.027 Avg. Tmax-0.00034 Avg. PCP

Table C2: Percentage deviation of yield of the east divisions of ND based on data from 1991-2000

Division	Year	Actual yield (tons/ha)	Predicted yield (tons/ha)	Difference (tons/ha)	Ratio	Deviation (%)
2	2001	1.80	2.22	0.42	1.24	19.04
	2002	1.75	2.28	0.53	1.30	23.11
	2003	2.53	2.23	-0.30	0.88	13.43
	2004	2.71	2.27	-0.44	0.84	19.18
3	2001	2.24	2.17	-0.07	0.97	3.11
	2002	2.34	2.21	-0.13	0.94	5.99
	2003	3.18	2.19	-0.99	0.69	45.14
	2004	3.31	2.23	-1.08	0.67	48.59
5	2001	1.93	2.18	0.25	1.13	11.45
	2002	1.60	2.24	0.64	1.40	28.62
	2003	2.83	2.21	-0.62	0.78	28.24
	2004	2.89	2.25	-0.64	0.78	28.56
6	2001	2.79	2.14	-0.65	0.77	30.37
	2002	2.37	2.19	-0.18	0.92	8.39
	2003	3.57	2.18	-1.39	0.61	63.96
	2004	3.61	2.21	-1.40	0.61	63.43
9	2001	2.95	2.13	-0.82	0.72	38.51
	2002	1.96	2.19	0.24	1.12	10.76
	2003	3.25	2.18	-1.07	0.67	48.81
	2004	3.32	2.23	-1.09	0.67	48.60

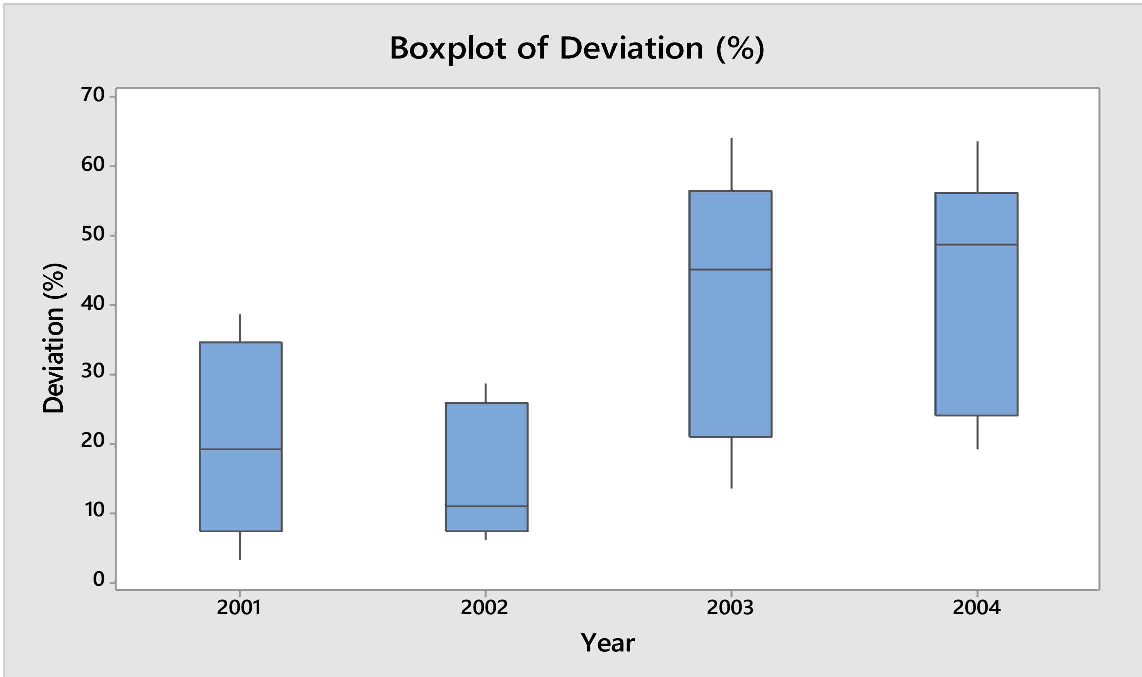

Fig C3: Box plot showing percentage deviation of yield from 2001-2004

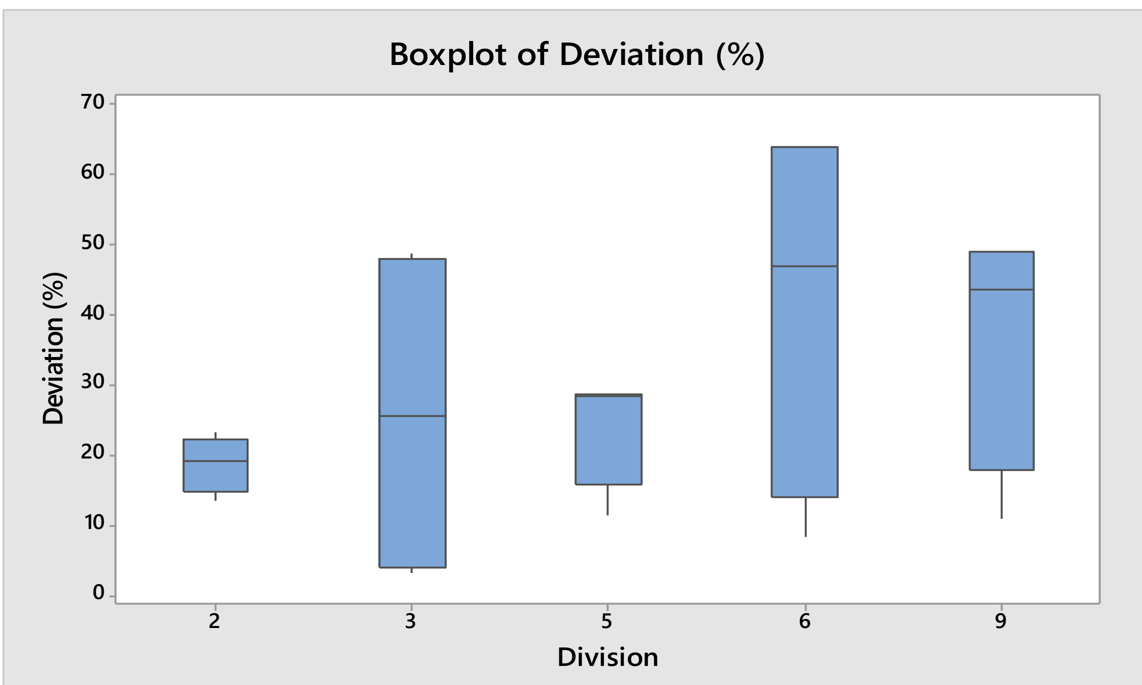

Fig C4: Box plot showing percentage deviation of yield in different divisions of ND

C.3. East Region: Cross Validation 3

Estimation dataset: 1981-1990

Prediction dataset: 1991-1994

Regression Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	5.2507	1.75024	6.36	0.001
Avg. Tmin (C)	1	0.1486	0.14858	0.54	0.466
Avg. Tmax (C)	1	1.1926	1.19264	4.33	0.043
Avg. PCP (mm)	1	0.0021	0.00212	0.01	0.930
Error	46	12.6578	0.27517		
Total	49	17.9085			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.524566	29.32%	24.71%	12.95%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	8.16	2.35	3.47	0.001	
Avg. Tmin (C)	0.173	0.236	0.73	0.466	6.60
Avg. Tmax (C)	-0.333	0.160	-2.08	0.043	7.59
Avg. PCP (mm)	0.00074	0.00839	0.09	0.930	2.35

Regression Equation

Spring Wheat yield=8.16+0.173 Avg. Tmin-0.333 Avg. Tmax + 0.00074 Avg. PCP

Table C3: Percentage deviation of yield of the east divisions of ND based on data from 1981-1990

Division	Year	Actual yield (tons/ha)	Predicted yield (tons/ha)	Difference (tons/ha)	Ratio	Deviation (%)
2	1991	1.88	2.20	0.32	1.17	14.51
	1992	2.37	2.42	0.05	1.02	2.20
	1993	2.27	2.84	0.57	1.25	20.06
	1994	2.29	2.17	-0.12	0.95	5.37
3	1991	2.48	2.38	-0.10	0.96	3.99
	1992	3.44	2.84	-0.59	0.83	20.91
	1993	1.78	2.98	1.20	1.68	40.34
	1994	1.96	2.44	0.48	1.24	19.58
5	1991	2.05	2.18	0.13	1.06	5.90
	1992	2.52	2.35	-0.17	0.93	7.16
	1993	2.10	2.87	0.77	1.37	26.93
	1994	2.11	2.30	0.19	1.09	8.11
6	1991	2.59	2.23	-0.36	0.86	16.31
	1992	3.24	2.53	-0.71	0.78	28.17
	1993	1.99	2.77	0.79	1.40	28.43
	1994	2.15	2.30	0.16	1.07	6.77
9	1991	2.09	2.28	0.19	1.09	8.36
	1992	3.11	2.48	-0.63	0.80	25.38
	1993	2.00	2.86	0.86	1.43	30.12
	1994	2.13	2.27	0.14	1.07	6.34

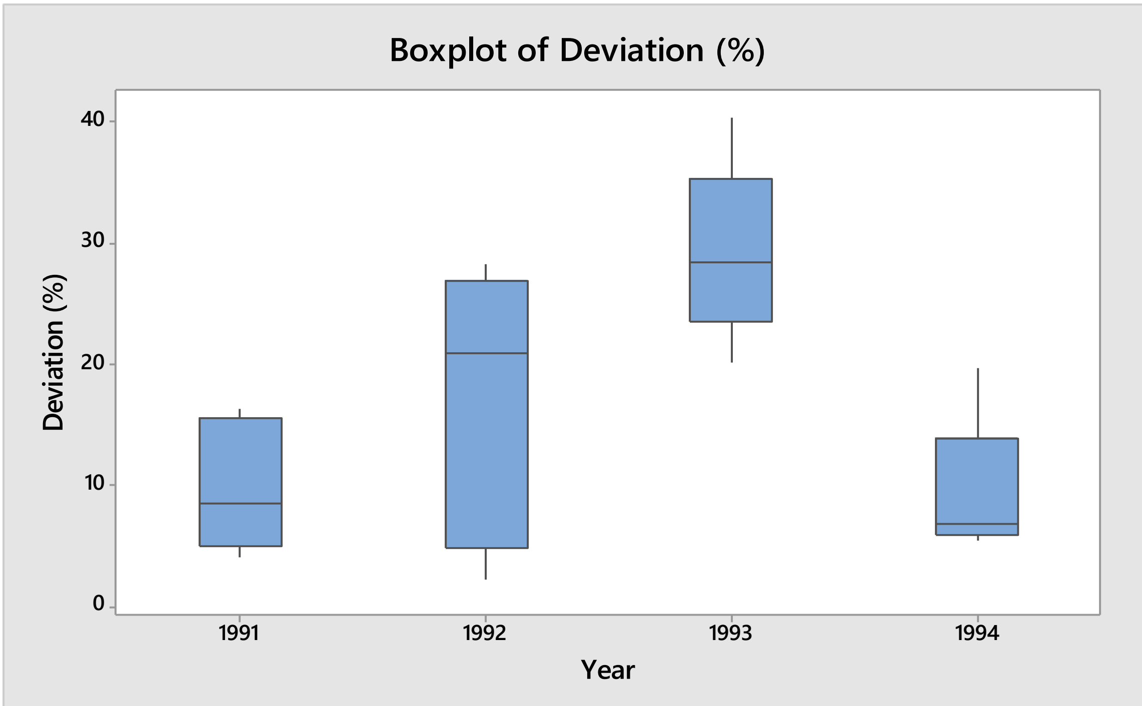

Fig C5: Box plot showing percentage deviation of yield from 1991-1994

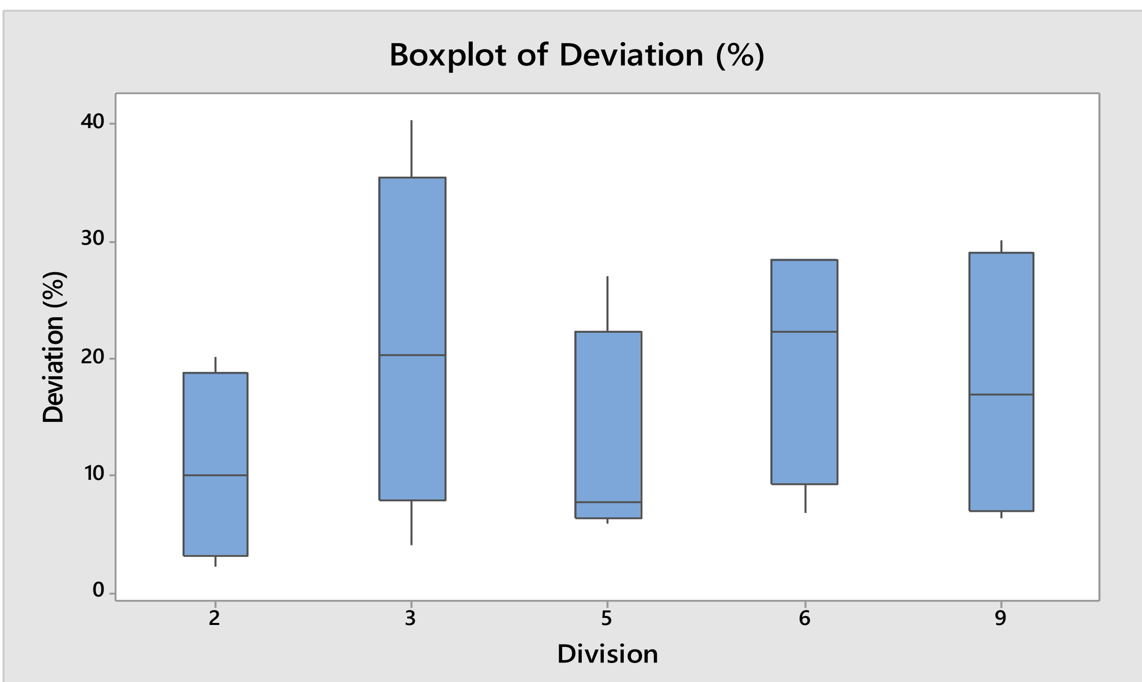

Fig C6: Box plot showing percentage deviation of yield in different divisions of ND

C.4. West Region: Cross Validation 1

Estimation dataset: 2001-2010

Prediction dataset: 2011-2014

Regression Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	5.8711	1.9570	13.11	0.000
Avg. Tmin (C)	1	0.2628	0.2628	1.76	0.193
Avg. Tmax (C)	1	1.5683	1.5683	10.50	0.003
Avg. PCP (mm)	1	0.1616	0.1616	1.08	0.305
Error	36	5.3749	0.1493		
Total	39	11.2460			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.386398	52.21%	48.22%	41.25%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	9.05	2.08	4.35	0.000	
Avg. Tmin (C)	0.252	0.190	1.33	0.193	5.27
Avg. Tmax (C)	-0.417	0.129	-3.24	0.003	4.89
Avg. PCP (mm)	0.00950	0.00913	1.04	0.305	2.48

Regression Equation

Spring Wheat yield=9.05+0.252 Avg. Tmin-0.417 Avg. Tmax+0.00950 Avg. PCP

Table C4: Percentage deviation of yield of the west divisions of ND based on data from 2001-2010

Division	Year	Actual yield (tons/ha)	Predicted yield (tons/ha)	Difference (tons/ha)	Ratio	Deviation (%)
1	2011	1.86	3.12	1.26	1.67	40.24
	2012	2.71	1.84	-0.87	0.68	47.29
	2013	2.87	3.23	0.35	1.12	10.95
	2014	2.90	2.92	0.02	1.01	0.67
4	2011	1.85	2.88	1.03	1.55	35.68
	2012	2.78	1.40	-1.38	0.50	98.35
	2013	2.85	2.78	-0.07	0.98	2.53
	2014	2.97	2.72	-0.25	0.92	9.20
7	2011	1.50	2.53	1.03	1.69	40.74
	2012	2.51	0.94	-1.57	0.37	168.19
	2013	2.97	2.52	-0.45	0.85	17.77
	2014	2.83	2.61	-0.21	0.92	8.21
8	2011	1.44	2.88	1.44	2.00	49.97
	2012	2.71	1.39	-1.31	0.51	94.26
	2013	2.67	2.69	0.02	1.01	0.79
	2014	2.88	2.71	-0.17	0.94	6.21

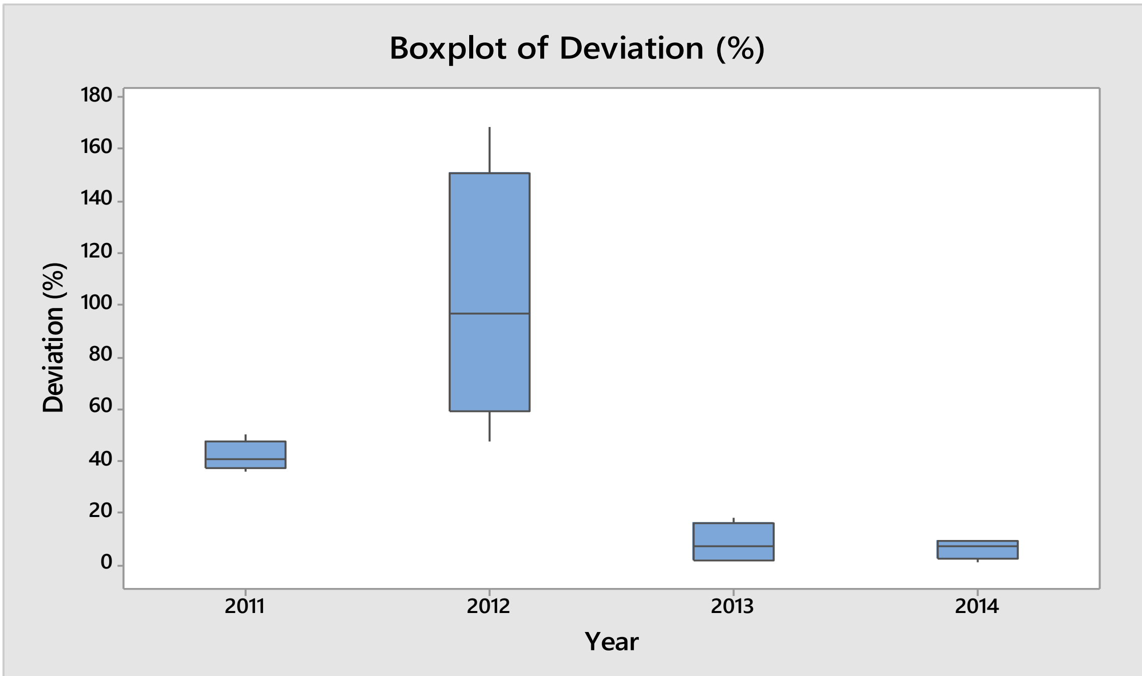

Fig C7: Box plot showing percentage deviation of yield from 2011-2014

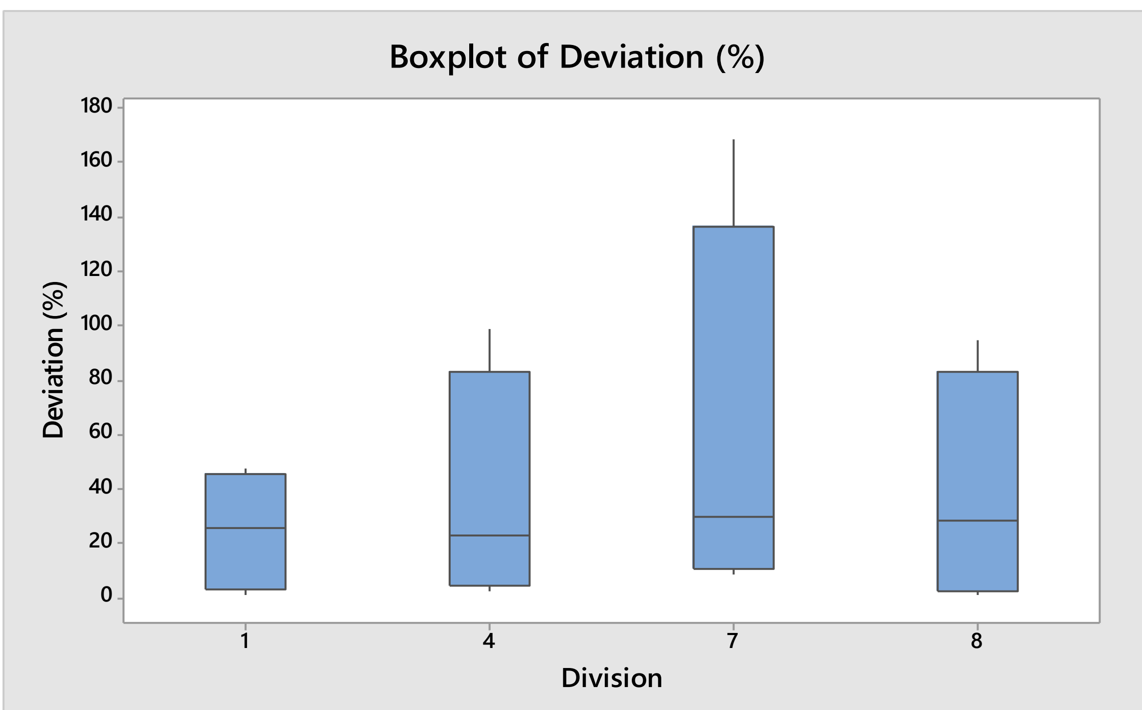

Fig C8: Box plot showing percentage deviation of yield in different divisions of ND

C.5. West Region: Cross validation 2

Estimation dataset: 1991-2000

Prediction dataset: 2001-2004

Regression Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	1.60946	0.53649	8.84	0.000
Avg. Tmin (C)	1	0.84539	0.84539	13.93	0.001
Avg. Tmax (C)	1	0.24627	0.24627	4.06	0.052
Avg. PCP (mm)	1	0.03716	0.03716	0.61	0.439
Error	36	2.18518	0.06070		
Total	39	3.79463			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.246373	42.41%	37.62%	30.79%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.46	1.62	0.28	0.780	
Avg. Tmin (C)	-0.378	0.101	-3.73	0.001	5.75
Avg. Tmax (C)	0.1853	0.0920	2.01	0.052	7.42
Avg. PCP (mm)	0.00430	0.00550	0.78	0.439	2.64

Regression Equation

Spring Wheat yield=0.46-0.378 Avg. Tmin+0.1853 Avg. Tmax+0.00430 Avg. PCP

Table C5: Percentage deviation of yield of the west divisions of ND based on data from 1991-2000

Division	Year	Actual yield (tons/ha)	Predicted yield (tons/ha)	Difference (tons/ha)	Ratio	Deviation (%)
1	2001	1.81	1.87	0.06	1.03	3.28
	2002	1.84	2.08	0.24	1.13	11.47
	2003	2.03	1.83	-0.20	0.90	10.96
	2004	2.52	1.99	-0.54	0.79	27.07
4	2001	2.17	1.87	-0.30	0.86	16.17
	2002	1.74	2.09	0.36	1.21	17.04
	2003	2.19	1.86	-0.33	0.85	17.51
	2004	2.20	2.25	0.05	1.02	2.19
7	2001	2.48	2.01	-0.47	0.81	23.33
	2002	1.15	2.23	1.08	1.93	48.32
	2003	1.80	1.97	0.18	1.10	8.93
	2004	1.78	2.33	0.55	1.31	23.75
8	2001	2.18	1.72	-0.46	0.79	26.68
	2002	0.99	1.99	1.00	2.01	50.20
	2003	1.79	1.75	-0.04	0.98	2.27
	2004	1.97	2.09	0.13	1.07	6.19

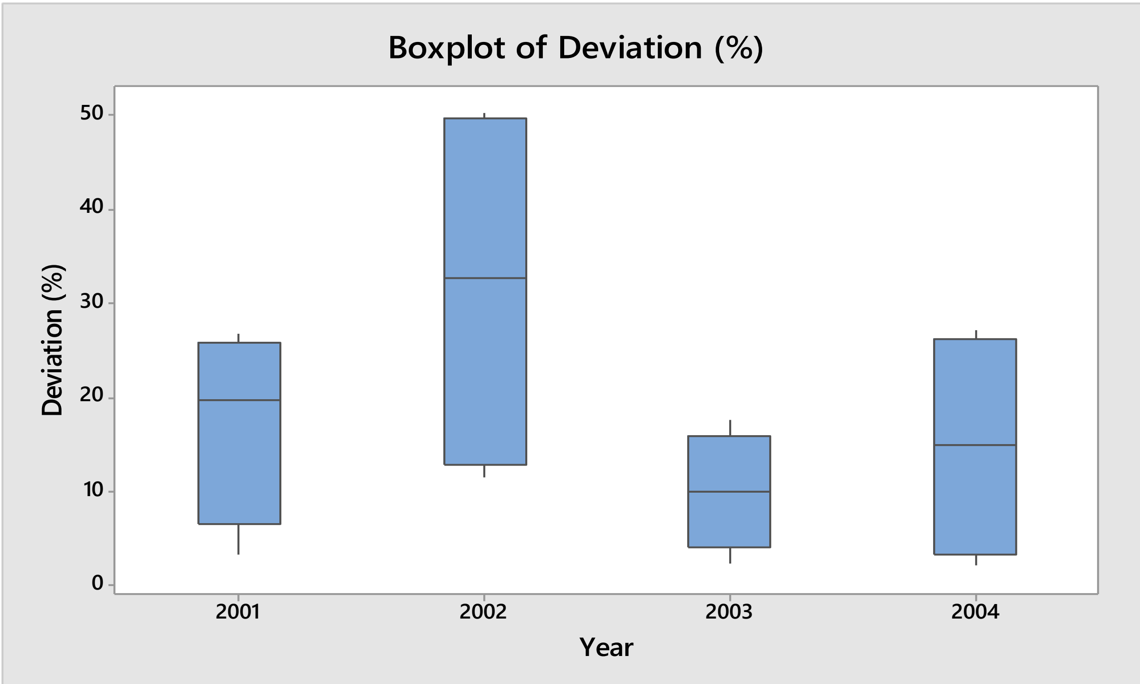

Fig C9: Box plot showing percentage deviation of yield from 2001-2004

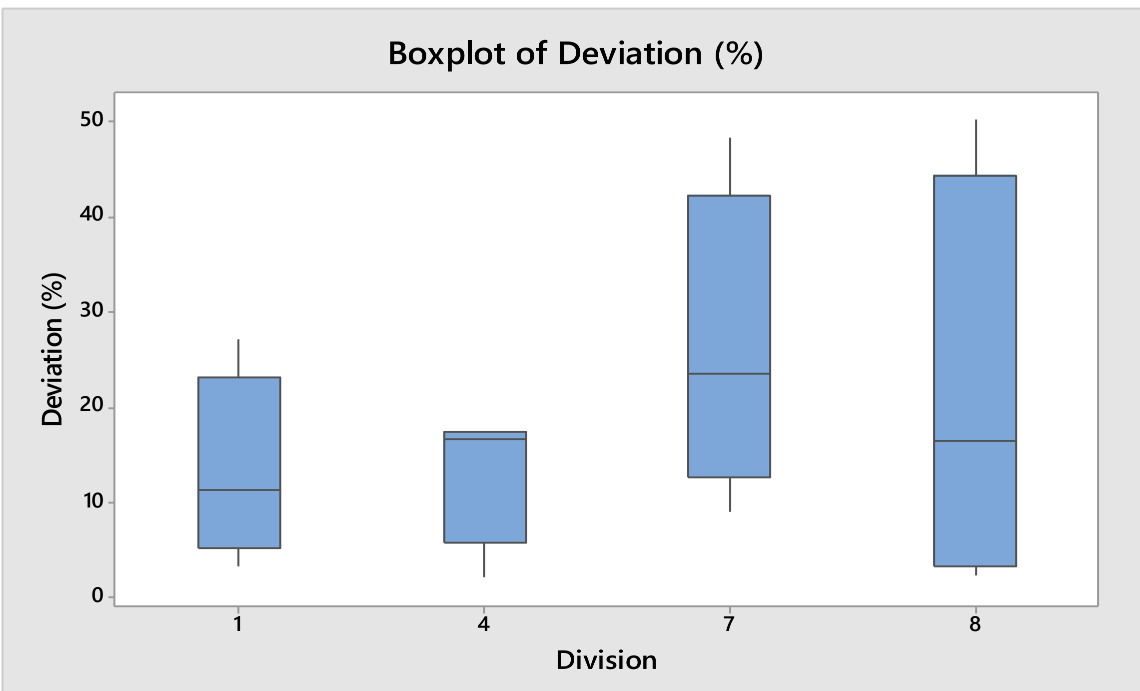

Fig C10: Box plot showing percentage deviation of yield in different divisions of ND

C.6. West Region: Cross Validation 3

Estimation dataset: 1981-1990

Prediction dataset: 1991-1994

Regression Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	4.88770	1.62923	22.52	0.000
Avg. Tmin (C)	1	0.02180	0.02180	0.30	0.586
Avg. Tmax (C)	1	0.15004	0.15004	2.07	0.158
Avg. PCP (mm)	1	0.14738	0.14738	2.04	0.162
Error	36	2.60400	0.07233		
Total	39	7.49170			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.268948	65.24%	62.35%	53.25%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	5.55	1.69	3.29	0.002	
Avg. Tmin (C)	-0.098	0.178	-0.55	0.586	7.78
Avg. Tmax (C)	-0.162	0.112	-1.44	0.158	12.26
Avg. PCP (mm)	0.00941	0.00659	1.43	0.162	3.53

Regression Equation

Spring Wheat yield=5.55-0.098 Avg. Tmin-0.162 Avg. Tmax+0.00941 Avg. PCP

Table C6: Percentage deviation of yield of the west divisions of ND based on data from 1981-1990

Division	Year	Actual yield (tons/ha)	Predicted yield (tons/ha)	Difference (tons/ha)	Ratio	Deviation (%)
1	1991	1.92	1.76	-0.16	0.92	8.90
	1992	2.66	2.06	-0.60	0.77	29.09
	1993	2.52	2.54	0.03	1.01	0.98
	1994	2.34	1.68	-0.66	0.72	39.16
4	1991	1.68	1.49	-0.19	0.89	12.78
	1992	2.42	1.86	-0.57	0.77	30.59
	1993	2.29	2.41	0.13	1.05	5.19
	1994	2.27	1.47	-0.80	0.65	54.59
7	1991	1.68	1.48	-0.21	0.88	13.99
	1992	2.32	1.88	-0.44	0.81	23.43
	1993	2.23	2.38	0.14	1.06	6.08
	1994	2.13	1.48	-0.65	0.70	43.69
8	1991	1.48	1.33	-0.15	0.90	10.96
	1992	2.20	1.87	-0.33	0.85	17.45
	1993	1.89	2.47	0.58	1.31	23.49
	1994	1.90	1.51	-0.38	0.80	25.38

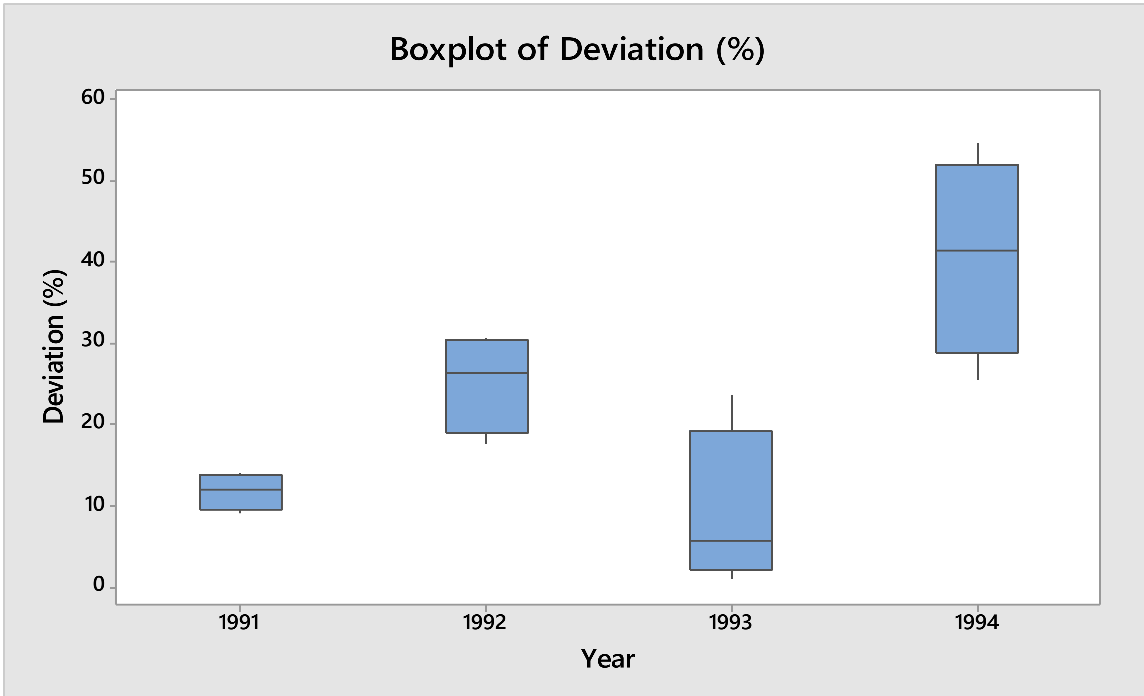

Fig C11: Box plot showing percentage deviation of yield from 1991-1994

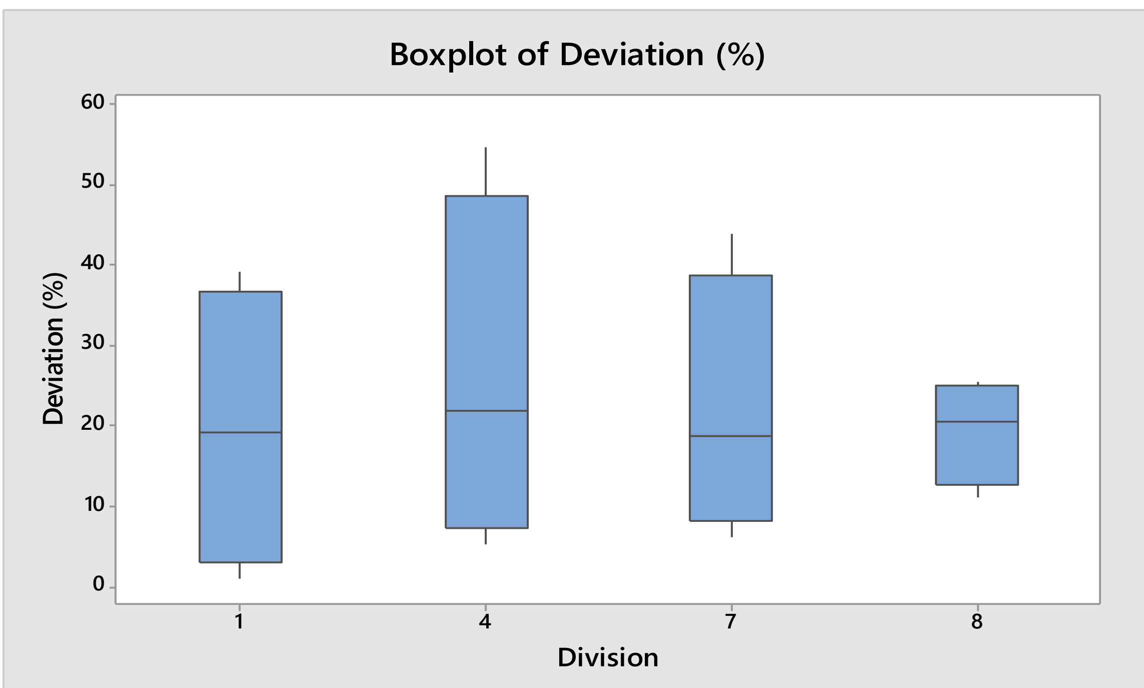

Fig C12: Box plot showing percentage deviation of yield in different divisions of ND