5-10-2003

Weather's Influence on the Phenological Period Length and Yield of Mississippi Soybeans

Sarah Kathleen McAtee

Recommended Citation

McAtee, Sarah Kathleen, "Weather's Influence on the Phenological Period Length and Yield of Mississippi Soybeans" (2003). *Theses and Dissertations*. 4999.
https://scholarsjunction.msstate.edu/td/4999

WEATHER'S INFLUENCE ON THE PHENOLOGICAL PERIOD LENGTH AND YIELD OF MISSISSIPPI SOYBEANS

By

Sarah Kathleen McAtee

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Geoscience
in the Department of Geosciences

Mississippi State, Mississippi

May 2003

WEATHER'S INFLUENCE ON THE PHENOLOGICAL PERIOD LENGTH AND YIELD OF MISSISSIPPI SOYBEANS

By

Sarah Kathleen McAtee

Charles L. Wax Professor of Geosciences (Director of Thesis)	Michael E. Brown Assistant Professor of Geosciences (Committee Member)
John C. Rodgers, III Assistant Professor of Geosciences (Committee Member)	John E. Mylroie Professor of Geosciences Graduate Coordinator of the Department of Geosciences
Mark S. Binkley Professor and Head of the Department of Geosciences	Philip B. Oldham Professor and Dean of the College of Arts and Sciences

Name: Sarah Kathleen McAtee

Date of Degree: May 10, 2003

Institution: Mississippi State University

Major Field: Geoscience

Major Professor: Dr. Charles L. Wax

Title of Study: WEATHER'S INFLUENCE ON THE PHENOLOGICAL PERIOD LENGTH AND YIELD OF MISSISSIPPI SOYBEANS

Pages in Study: 165

Candidate for Degree of Master of Science

The climate of Mississippi has been considered to be ideally suited for the production of soybeans. Many studies have shown the influence of weather on crops, but none that specifically attempt to pinpoint which aspects of weather have an impact on the Mississippi soybean crop. The purpose of this study was to determine what affect weather has on the phenological period length and yield of Mississippi soybeans. Data on bean phenological periods and yield used in this research were recorded as a part of soybean variety testing conducted at Delta Research and Extension Center in Stoneville, Mississippi from 1976-2000. The major statistical procedure used in this study was Pearson's Correlation Analysis that was used to determine any significant relationships between soybeans and weather. This study found that cooler temperatures and more moist conditions positively influence yield in Mississippi soybeans, while energy is more important in determining period lengths than water.

ACKNOWLEDGEMENTS

I would like to express my thanks to my committee members, Dr. Michael Brown and Dr. John Rodgers, for their help in completing this project. I would especially like to thank my major professor, Dr. Charlie Wax, for his patience, effort, and good jokes which were greatly needed to finish this project.

TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

TABLE Page

LIST OF FIGURES

FIGURE Page

FIGURE .... Page

CHAPTER I

INTRODUCTION

The southern region of the United States, commonly known as “The South”, has many attributes that give it its distinctive essence. For example, the unique dialect known as the southern drawl, the renowned “Southern hospitality”, and a very well developed sense of place that tends to foster close-knit families and communities are all distinguishing characteristics of the southern states. However, more than anything else, The South is known for its climate.

Mississippi, located in the middle of the region, has a climate characterized by extreme heat in summer and by the absence of severe cold in winter. The ground rarely freezes and outdoor activities are generally favored year-round. Cold spells are usually of short duration and the growing season is long; rainfall is plentiful though not reliably distributed throughout the year. Dry spells usually accompany harvest time when they are most needed, but drought can be a damaging aspect of the climate. While thunderstorms, tornadoes, and hurricanes can cause severe damage, they affect only a small part of the state at any time and protective measures can be taken against them.

The climate of Mississippi is controlled by the landmass to the north, its subtropical latitude, and the Gulf of Mexico to the south. The location and seasonal intensity of the Bermuda High can also dominate an entire season in the state. These controls produce the Humid Subtropical climate type, typified by mostly mild winters without extended periods of temperatures below freezing; long, hot summers; and no routinely recurring wet or dry season. This climatic setting has given the state a traditional orientation toward agriculture and forestry.

Given the number of factors controlling climate in Mississippi, the state is characterized by a “feast or famine” situation in many years, with the “average” traits seemingly never prevailing. For example, an active Subtropical Jet Stream during the winter season can aid the persistent development of midlatitude cyclones in the Gulf of Mexico or in Texas, which move over or near the state and bring warm, wet winter weather spells. A strong Bermuda High in the summer can cause devastating drought conditions for weeks or months. Mississippi’s climate is also controlled to some extent by more global mechanisms and teleconnections such as the El Nino and La Nina phenomena, which can bring either warm, wet or cold, dry winter and spring seasons, and which can also influence the occurrences of tornadoes and hurricanes for the state.

Figures 1 and 2 show the variability of the climate in the “Delta” region of Mississippi, the most ubiquitously agricultural part of the state. Figure 1 depicts the annual temperature departure from the “average” temperature for that area of the state. This graph shows that the annual average temperatures often fluctuate greatly with one much warmer year immediately followed by an equally cooler year. Figure 2 shows the annual precipitation departure from the “average” precipitation for the Delta. This graph also illustrates the “feast or famine” nature of the state and

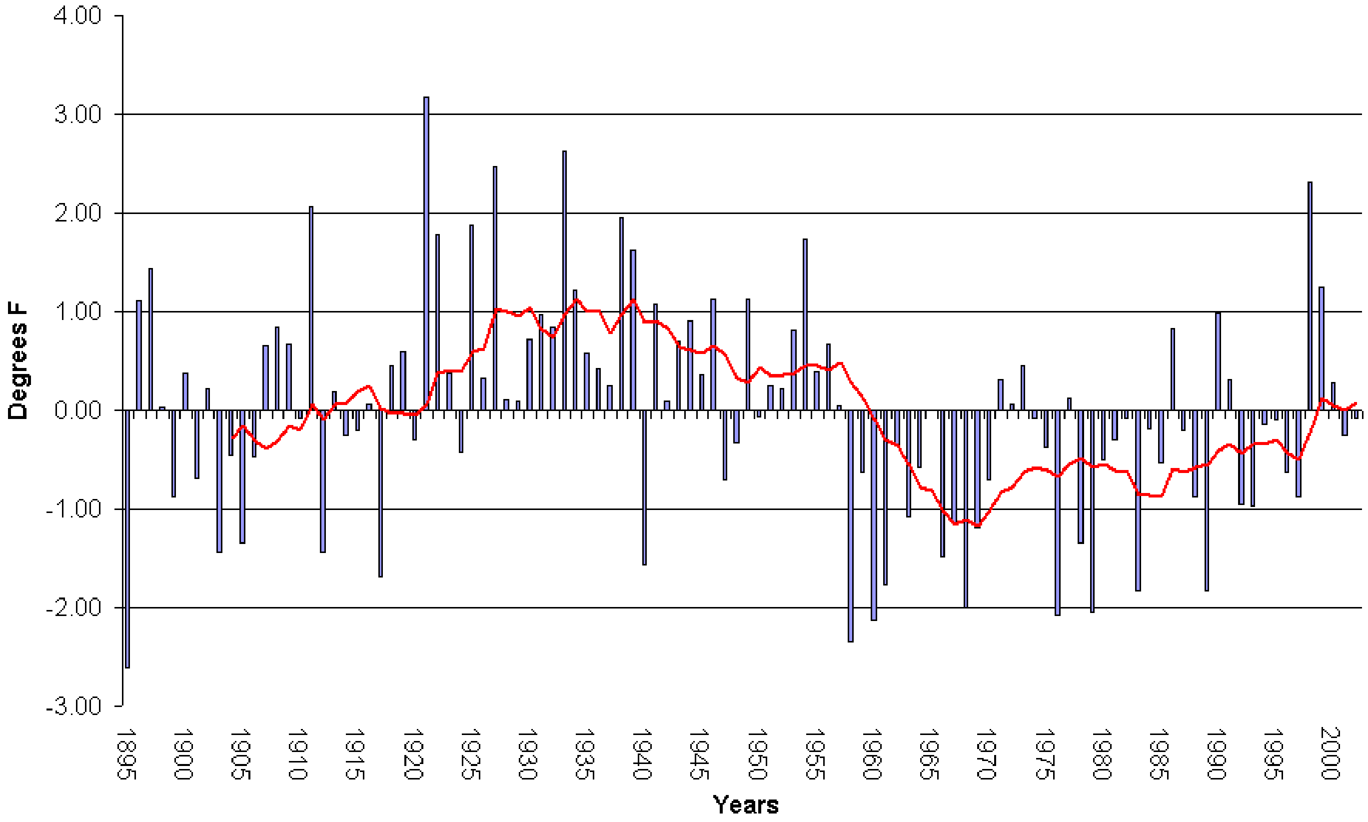


Figure 1: Annual Temperature Departure from Normal for the Lower Delta of Mississippi
Bars represent the annual departure from the mean, the line is the 10 year running mean

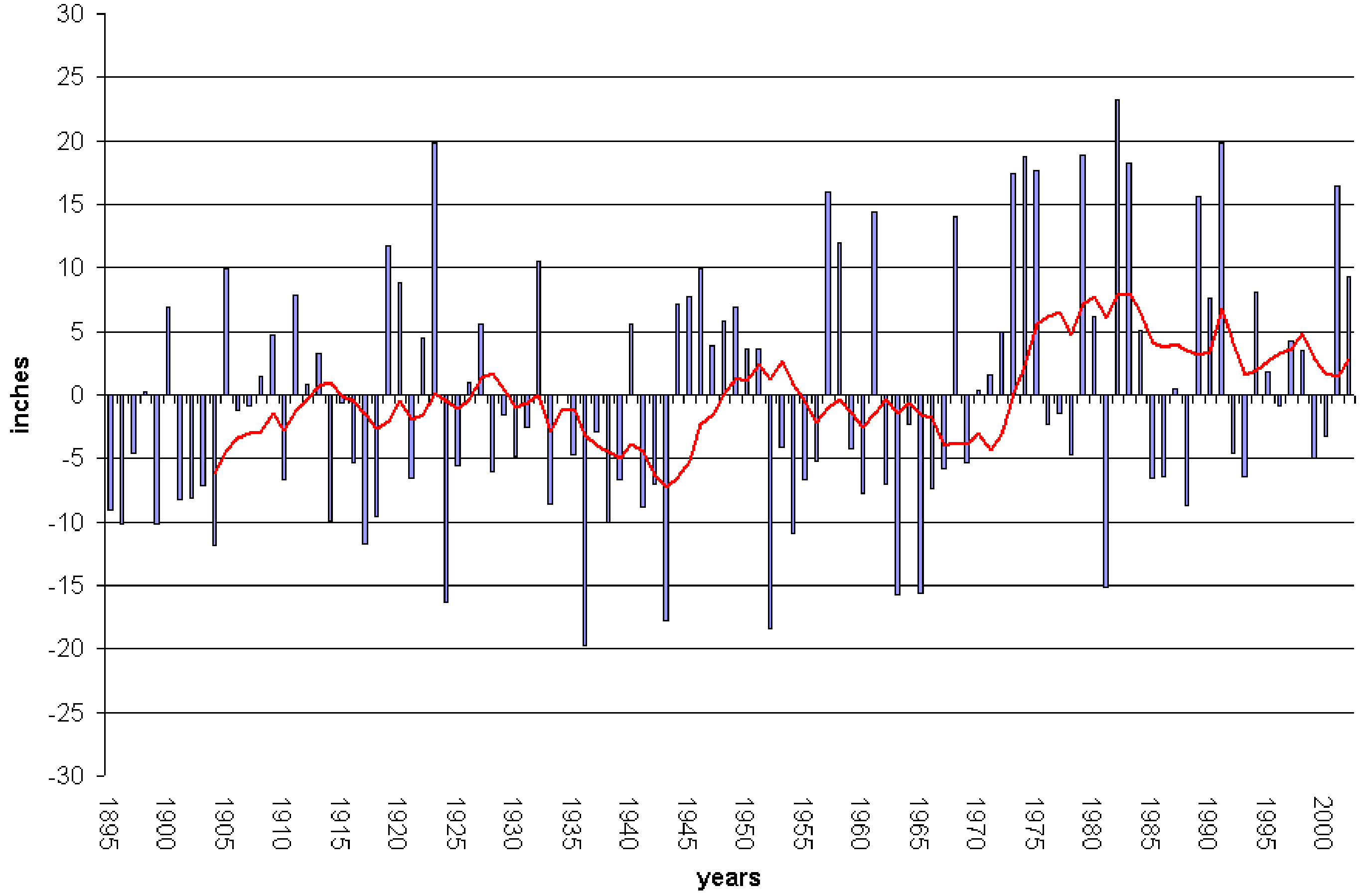


Figure 2: Annual Precipitation Departure from Normal for the Lower Delta of Mississippi
Bars represent annual departure from the mean; the line is the10 year running mean

shows that often there are a series of more moist years followed by a period of drought.

In the warmer season (and throughout much of the rest of the year) prevailing southerly winds provide humid, semitropical conditions often favorable for afternoon thunderstorms. These storms produce an average of about 25% of the state's annual precipitation, and are at times accompanied by locally violent and destructive winds. High humidity, combined with hot days and nights, generally produces discomfort from May to September, with dew point temperatures routinely in the upper 70s. When the pressure distribution is altered so as to bring westerly or northerly circulation, periods of hotter and drier weather interrupt the prevailing humid condition. It is also not unusual for these circulation shifts to produce very pleasant spells of weather in May, June, and September, with dew points dropping into the 30s for a few days.

In the colder season the state's weather is dominated by the positions of the Polar and Subtropical Jet Streams, and their subsequent control over the passages of warm and cold fronts of midlatitude cyclones. These frontal passages alternately subject the state to warm tropical air and cold continental air, in periods of varying length. However, cold spells seldom last over three or four days. The ground rarely freezes, and then mostly in the north and only a few inches deep. Continental Polar and Arctic air behind cold fronts is usually considerably modified by the time it enters the state, but these air masses can occasionally bring large and rather sudden drops in temperature. When the upper air circulation is configured to support the intrusion of bitterly cold Arctic air masses into the state, a situation referred to as "The Siberian Express", extreme cold spells may occur. Temperatures in the northern part of the state have fallen to -19^0F during one such occurrence. Conversely, it is not unusual for warm fronts to bring air masses with temperatures in the 80s into the state during January and February.

The normal annual temperature ranges from 61^0F in the northern border counties to 67^0F in the coastal counties. Daily highs in January average 50^0F in the north and 61^0F along the coast. Daily minimum temperature in January averages 30^0F and 43^0F in the north and along the coast, respectively. July daily average highs are about 93^0F and 90^0F in the north and on the coast, respectively. July daily minimum temperatures average 70^0F and 75^0F from north to south, respectively. Temperatures of 90^0F or higher occur an average of just 55 days per year on the immediate Gulf coast under the ameliorating effect of the relatively cooler Gulf waters. However, there is a rapid increase in number of days 90^0F or higher inland from the coast, reaching a maximum of over 100 approximately 50 miles inland. Temperatures of 32^0F or lower occur on average about 13 days a year on the immediate Gulf coast, increasing to a maximum of around 73 days on the Tennessee border.

Mean annual precipitation ranges from 50 inches along the northern border to 65 inches along the coast, averaging around 56 inches statewide. During the freeze-free season, rainfall ranges from 23-25 inches in the Delta region to 36-38 inches in the southeast. This distribution discourages the growth of crops with critical water requirements, such as corn, in much of the Delta, but it is beneficial for cotton. Conversion from row crops to cattle in large areas in the northern part of the state is due, at least in part, to insufficient or poorly distributed rainfall. Irrigation is being increasingly practiced because the abundant rainfall does not always come in the time of greatest need. It is not unusual for Mississippi to experience general agricultural droughts, especially during the summer season. Stream flow and precipitation records indicate at least nine significant periods of extended drought in the state since 1930 .

Despite the “feast or famine” nature of the climate of the Mississippi, the primary economic endeavor of the state since its settlement by Europeans has been agriculture. In the 1700s farmers in Mississippi attempted to grow tobacco and indigo (two high paying cash crops at the time) but quickly found out that the climate of Mississippi was not favorable to the growth of either of these crops. Both indigo and tobacco require moist soils throughout the growing season; however, during this time of the year in Mississippi the climate is more reluctant to deliver a steady and dependable supply of rainfall, and the indigo and tobacco crops dried up. However, cotton (and slavery) was soon introduced into Mississippi and proved ideal for the climate. A wet spring followed by a dry growing and harvest period were the perfect conditions for growing cotton, and in the early and mid 1800s the Delta region of Mississippi rose to agricultural prominence on the back of cotton, slavery, and the plantation system.

Even after the Civil War and the abolishment of slavery, cotton remained the number one cash crop for Mississippi well into the mid 1900s. However, declining cotton prices and a series of bad harvests in the 1940s led to the need to diversify Mississippi's crops. After World War II, two new agricultural pursuits that would eventually become extremely economically important to Mississippi were begun in the state—catfish farming and soybeans. These two crops have proven to be ideally suited to the climate of Mississippi and have had a great impact on the economy of the state. Although cotton is still grown extensively in the state today, Mississippi has successfully diversified into other agricultural areas of which soybeans have become an important part.

In addition to the advent of new crops into Mississippi, the implementation of precision agriculture has also served to make the farming industry in the state more profitable. Nowak (1998) defines precision agriculture as "the process of turning spatial and temporal data into information to drive agronomic decisions on a site-specific basis." An important component of precision agriculture is the influence that weather has on crops. Knowledge of how weather affects the growth and yield of crops can be used to make that crop more profitable.

Many studies on how weather affects crops in Mississippi have shown how greatly the weather can influence a crop. For example, in a study by Wax, Rasberry and Matta (1987), the effect of late freezes on peach crop damage in Mississippi was studied. They found that during all years throughout Mississippi there exists the possibility of a late freeze that either substantially reduces crop yield or results in total crop loss. In the late winter in Mississippi it is not uncommon to have a warm spell (one that would promote budding of the peach trees) followed by a cold snap and even a killing freeze. Wax, Rasberry and Matta found that a freeze occurs at least every 2 out of 3 years during the peach bloom period, even in the southern areas of the state. 28^{o}F freezes have occurred in 54% of the years (during which 10% of the peach blossoms would be damaged) and 25^{o}F freezes have occurred in 26% of the years (which results in 90% of the blossoms being damaged). With this knowledge of how the climate affected peach crops, the researchers were able to make recommendations on how to protect the peach trees from frost damage (such as providing good air drainage away from the trees and keeping soils moist).

In another study by Pote and Wax (1986), the weekly crop water demand was compared to the probability of rainfall (at 80% and 50% probability levels) during each week of the growing season in order to determine the average weekly supplemental irrigation that would be required. Five Mississippi crops were used in this study—corn, cotton, sorghum, doublecropped soybeans, and early soybeans. The expected precipitation for each week during the growing season was calculated and compared to the crop water demand for that week. From these comparisons the authors were able to devise a more accurate system of irrigation based on what the climate was expected to deliver during a given week of the growing season, thus saving the farmer from the expense and waste of over- watering.

Although there have been many studies on weather and Mississippi crops, there has been no study on specifically how weather influences the soybean crop in

Mississippi. Knowing how the climate of Mississippi impacts the development and yield of soybeans can only serve to aid farmers in their production of the crop.

Today in Mississippi soybeans are a large and economically viable crop. In 1999 soybeans were the second largest crop in the state, totaling $214 million in cash receipts, falling behind only cotton at $474 million (MASS, 2001). Mississippi ranks 16th in the nation for the production of soybeans, and out of 11.1 million acres of farmland in Mississippi, about 2 million acres are devoted each year to the cultivation of the crop (MASS, 2001). Given that soybeans are so important to the economic health of the state and that weather is so important to successful crop production, it would be worthwhile to determine what type of relationships exist between weather and the production of the crop. This knowledge could then be used to make the Mississippi soybean crop more profitable.

There are certain well-known effects that weather has on soybean crop development. For example, soybeans need a total of about 20-25” of water throughout the growing season and, in order for rapid emergence of the plant to occur, soil temperatures must range between 68°-86°F (MCES, 2001). These are well-known effects of weather on crop development, but are there critical periods of growth during which certain weather influences are more marked than during other times? What, if any, effects do weather variables or combinations of weather variables have on the time it takes soybeans to move from one developmental stage to another and on the resulting yield? Does weather-induced variation in length of developmental stages effect total yield? Can knowledge of these effects help make production of the crop in Mississippi more precise, dependable, and profitable?

Although it is known that weather does impact crops, no study has ever been done that determines which weather variables are most critical to soybean development and yield in Mississippi. The objective of this research is to determine what impact, if any, various weather variables have on the phenological period lengths and yield of unirrigated soybean crops grown in the Mississippi Delta region. Three specific objectives are as follows: 1) to determine if there is a relationship between weather and phenological period length; 2) to determine if there is a relationship between weather and yield; and 3) to determine if there is a relationship between phenological period length and yield. It is hypothesized that there is a relationship between weather and phenological period length, weather and yield, and phenological period length and yield.

The value of this research is in the potential for optimizing the productivity of soybeans in the sate and consequently increasing the size and economic value of the crop. For example, if rainfall is found to be a major factor in the length of a certain growth stage, then it may be possible to manipulate water availability through irrigation at precise times to accelerate the crop’s development by shortening that particular stage. Another management strategy, planting earlier to catch the more reliable early season rainfall, could cause peak crop water demand to then be reached at a point earlier in the growing season when that demand is more likely to be met. At that point, the peak demand would be occurring ahead of the normal hot and dry weather, characteristic of late summer in Mississippi. The possibility of drought stress on the crop could therefore be minimized, with a concurrent increase in quantity and quality of the crop.

CHAPTER II

BACKGROUND INFORMATION AND LITERATURE REVIEW

Around 8500 B.C., the people of Southwest Asia became the earliest known farmers as they cultivated the very first domesticated crops of wheat, peas, and olives (Diamond 1999). Ever since this “invention” of agriculture (which took place around the world at different times), food production has been at the mercy of the weather. No doubt these ancient farmers had to deal with the same floods and droughts that still plague farmers today. More recently, however, scientists have sought to understand more completely the interactions between climate and crops. J. Y. Wang (1984) defined agrometeorology as:

> the study of states and processes of the physical environment (air, water and soil) as related to the living organisms that comprise and are associated with agricultural operations. It is concerned with the interpretation and dissemination of meteorological information for use in practical and effective agricultural management

By understanding how weather impacts crops and which aspects of weather (such as energy and water) influence crop growth and yield most prominently, researchers could potentially determine ways to increase yield and productivity through manipulation of those variables that are under human control.

The climate places distinct limitations on what kinds of crops can be grown (economically) at a given location. Temperature, for example, has a very profound effect on crops. Each plant has both a threshold temperature and an optimal temperature that set limits for that plant's growth. Research has shown that crop development is temperature dependent and that each species and variety of plant has certain temperature requirements (Thompson and Perry, 1997). For example, Griffiths and Driscoll (1982) note that for successful cultivation of apples (a good yield), a cold winter is necessary, requiring about 1000 hours below 45°F. For a good yield of bananas, however, a monthly temperature mean of over 70°F is required, with 80°F being the optimal temperature for this crop. The implications of this are, of course, that bananas cannot be grown in Washington State with any hope of an economic success. The opposite is also true; apple trees would not be expected to thrive and produce fruit in a tropical rainforest.

Critchfield (1983) states that for the mid-latitude grain belts, the highest yields generally occur when summers are cooler than average for a specific year. Often summers with cooler temperatures are summers with increased amounts of rainfall, which reduces drought stress on the plants and allows for greater storage of the photosynthetic products, resulting in higher yield. Researchers have also found that the highest yields of soybeans are associated with air temperatures that are below normal in July and August but with precipitation that is above normal for those months (Mather, 1974).

In addition to yield, there is evidence that climate and weather impact the phenological period length of crops. Phenological stages are distinct periods of development within the lifecycle of any living organism during which a marked change occurs in that organism. Mather (1974) defines phenology as "the relation of climate to periodic biologic activity in either plants or animals". More simply stated phenology is the study of how climate influences the different developmental stages of a plant. Soybeans, for example, have very distinct phenological periods, and Heatherly (2002) divided these periods into plant to bloom (P-B); bloom to podset (B-P); podset to seedform (P-S); seedform to fullseed (S-F); and fullseed to maturity (F-M). Since early on in soybean studies, it has been thought that each of these stages of soybean growth is influenced by the weather that occurs during the length of the stages.

Kincer and Mattice (1928) found that certain weather influences were more marked during critical periods of soybean growth than during other times. By the 1950s researchers had begun to group soybean growth data by climatically and agriculturally homogeneous regions in order to more clearly discern the effects of weather on soybean growth stages (Sanderson, 1954). Odell (1959) used phenological growth stages as specific time intervals, and because of the annual temporal variability of these growth stages, he suggested that weather variables from the same time periods must be used to pinpoint the effects of those variables on the growth stages. In 1963 Watson noted that detailed knowledge of the ways weather affected certain growth stages of soybeans could result in the prediction of soybean yield from weather records. All these earlier studies point out the long-held and strong expectation that each phenological stage of soybean growth is influenced by weather.

In a more recent study done by Logan, Mueller, and Graves (1998), weather and its influence on phenology and yield were examined as factors in determining if the Early Soybean Production System (ESPS) would be a better alternative for Tennessee, as opposed to the current recommended soybean system in place. The researchers hypothesized that the ESPS could be planted earlier than the recommended system and might thereby avoid any late season drought. However, they concluded that ESPS was not a viable alternative to the recommended production system in Tennessee because the weather conditions in Tennessee tended to lengthen the phenological periods of the ESPS soybeans and depress yields. The recommended production system, even when subjected to the most stressful environment (high temperatures and drought), still had higher yields than the ESPS soybeans under more favorable conditions.

Drury and Tan (1995) took a more long-term approach to studying weather's effect on corn yield over a 35-year period. Although a number of weather variables were included in the study (precipitation, maximum and minimum temperatures, and evapotranspiration), they concluded that the only variable that influenced crop yield was growing season precipitation. However, it is important to note that yield was positively correlated with growing season precipitation only when the corn crop was fertilized. As another example, Swanson and Nyankori

(1979) studied the relationship between corn and soybean yields over a 27-year period in Illinois and the adoption of new technology by farmers and the impacts of weather. Swanson and Nyankori wanted to determine if yield trends, which should be increasing over the 27-year period due to the new technology, were at all affected by the weather that the area experienced during that time period. They concluded that temperature and precipitation variation during that period acted to dampen yield increases that would otherwise have occurred due to the adoption of new technologies by farmers.

Early thought on soybean growth was that the crop's development was totally independent of temperature and moisture and was governed by only daylength (photoperiod). It was subsequently found that warm, moist soil (68^0-86^0 F) was needed for emergence, and that warmer temperatures resulted in faster emergence. It was further learned that up until beginning bloom, the beans could tolerate short periods of drought without influencing yield. However, adequate soil moisture must exist from beginning bloom until beans are fully touching in the pods. A strategy used in Mississippi in recent years has been to plant more northerly maturity groups (IV and V), allowing earlier planting dates and faster maturation, shifting the crop away from the greatest threat of drought which occurs later in the growing season.

As described earlier, Mississippi is located in the humid, sub-tropical climate region. Main characteristics of this climate type are temperate winters; long, hot summers; and rainfall evenly distributed through the year. This climate is generally recognized as conducive to good soybean production. During the growing season, slightly more than half of total annual precipitation occurs, but the majority of annual evaporation occurs during that same time, creating frequent drought conditions. Evaporation exceeds precipitation from about May through October in Mississippi. It is part of the normal climatic character of this area that evaporative demand of the atmosphere is greatest during the part of the year when precipitation is least reliable. For example, in the Delta during the week beginning June 28 each year over a 30-year period, precipitation averaged 1.09” but ranged from zero to 5.74”, with a standard deviation of 1.35” (Wax and Walker, 1985).

In recent years technological advancements have made weather data increasingly available and more easily analyzed by computer. These innovations make it more feasible to manage the volume of data required to associate time and site-specific weather data with actual plant phenological periods of entire crops over many years. It may now be possible to more accurately establish the relationships between phenological period length and weather, soybean yield and weather, and phenological period length and yield.

Although there have been many studies that show that weather has influenced some aspects of both crop phenological period length and yield, there has yet been no type of study done that specifically tries to determine how different weather variables occurring at discrete times in a crop’s life may affect Mississippi soybeans. This project will contribute to the existing body of knowledge by attempting to discern what aspects of weather are important in the phenological growth stages of soybeans as well as determining what weather conditions can lead to a larger yield.

CHAPTER III

METHODS AND PROCEDURES

Soybean data

Data on soybean phenological periods and yield used in this research were recorded as a part of soybean variety testing conducted at Delta Research and Extension Center in Stoneville, Mississippi from 1976-2000. Daily field observations were made to establish and record each growth stage of the soybeans. Data collected on the crops were variety type, soil type, year, irrigated or not, planting date, bloom date, podset date, seedform date, fullseed date, and maturity date.

In a typical year, multiple varieties were tested under different conditions of soil type, planting date, and irrigation. All varieties were common to maturity groups IV, V, VI, and VII, which are planted in Mississippi. This analysis was limited to the most commonly used groups (Mature Groups IV and V), and to those planted only on homogeneous soil types and not irrigated. Mature Group 4 contained 113 cases, and Mature Group 5 contained 133 cases. This resulted in a large data set, which was subsequently digitized into a delimited ASCII file and made available for this study. The digital database was transformed into a format compatible with weather data files.

Phenological period lengths were derived for each experimental crop from the observed dates of the beginning and end of each developmental stage (plant to bloom, bloom to podset, podset to seedform, seedform to fullseed, and fullseed to mature). Month and day data were converted into the Julian calendar system. The Julian system numbers days through the year sequentially, so that January 31 is number 31 in the Julian system and February 1 is number 32, February 2 number 33 and so on through the year until December 31, which is number 365. By using the Julian system, it is possible to subtract one date from another in order to determine how many days were in between those two dates. Phenological period lengths were determined in this way. For example, the Julian calendar planting date was subtracted from the bloom date to determine the length of the plant to bloom (P-B) period. This same procedure was followed to determine the lengths of each of the phenological periods. This information on each phenological period of each case was entered into an Excel spreadsheet in order to make it compatible with other parts of the study.

Climatological Data

Daily weather records of precipitation, evaporation, maximum and minimum temperature, and day length observed at Stoneville, Mississippi were used in this research. These data were entered into an Excel spreadsheet file to cover the period 1976-2000. These five measured variables were then used to derive twenty other weather variables: total precipitation (totP), precipitation days (Pdays), 0.8 pan evaporation (0.8PE), precipitation minus 0.8 pan evaporation (P-E), Degree Day 50 (DD50), Degree Day 60 (DD60), average minimum temperature (AvgMinT), average maximum temperature (AvgMaxT), absolute minimum temperature AbsMinT), absolute maximum temperature (AbsMaxT), average day length (AvgDayLn), the number of days with a maximum temperature above 90°F (+90 Days), and High Temperature 85°F--High Temperature 98°F (HT 85- HT 98).

These derived variables were determined by writing algebraic formulas in the Excel spreadsheet to determine their values. For example, total precipitation was determined by writing a formula that summed the daily precipitation data for the dates included in a given phenological period. To determine 0.8 pan evaporation, a formula was written in Excel that multiplied the daily recorded pan evaporation by 0.8, the constant derived for use in Mississippi in order to more accurately portray the actual amount of moisture loss (in inches) from the soil.

Heating Degree Day 50s and Heating Degree Day 60s measure the number of degrees over 50°F or 60°F for a given day's average temperature. For example, if one day the average temperature reaches 80°F, on that day 30 DD50s are accumulated and 20 DD60s are accumulated. In order to determine DD50s and DD60s, a formula was written in Excel that summed and accumulated the number of degrees over 50°F and 60°F, respectively, that the average daily temperature was on every day during the length of a given phenological period.

Average minimum temperature was found by writing a formula that calculated the mean of each day's minimum temperatures for a given phenological period. Average maximum temperature was found by writing a formula that calculated the mean each day's maximum temperatures for a given phenological period. Absolute minimum temperature was found by writing a formula in Excel that located the single lowest minimum temperature that occurred during a given phenological period. Absolute maximum temperature was found by writing a formula that located the single highest maximum temperature that occurred during a given phenological period. The number of days with a maximum temperature above 90°F was found by writing a formula that located and counted the number of days that had temperatures over 90°F in a given phenological period.

High Temperature 85 (HT85) is a measure of how many degrees over 85°F the absolute maximum temperature was in a single day. For example, if the absolute maximum temperature for one day was 90°F, then 5 HT 85s were accumulated for that day. HT 85 was found by creating a formula that summed and accumulated the number of degrees over 85°F the absolute maximum temperature was in a given phenological period. This same procedure was used to find the values for HT 86 through HT 98.

Data Manipulation, Quality Control, and Statistical Methods

Data Reduction

Through the assimilation of the measured weather variables and the computation of the derived variables, a massive weather data set was created for correlation with the phenological periods and yield. Data reduction and analysis of this massive amount of data and were made possible only through the use of computers. The main effort of this study was to associate the discrete beginning and ending dates of each phenological period with the corresponding weather that actually occurred between those dates. This tedious effort was accomplished by development of a computer algorithm that used Julian dates to assemble the raw weather data from multiple files and simultaneously calculate the derived variables for that phenological period.

The Excel spreadsheets containing weather and soybean data were linked and computer algorithms were designed to extract the weather data, based on certain dates, from the Excel database that was created containing the weather variables. As previously described, the beginning and ending of phenological periods were assigned Julian dates. A spreadsheet was then created that contained a column of the Julian dates down one side of the spreadsheet and a row of all the years of the study (1976-2000) across the top of the spreadsheet. For each given phenological period for a single case, an “x” was placed in each cell corresponding to the Julian dates for that phenological period and to the year in which that case occurred. This spreadsheet was linked to the database that contained the 25 weather variables. Excel was then programmed to extract the corresponding weather data and derived variables from the databases for the phenological period thus described.

After all the phenological periods for a given case had the corresponding weather variables associated with them, a “total” line was created that summed the total number of days it took the soybean to go completely through all of its phenological periods--planting to mature. The total line also summed the total precipitation, the number of precipitation days, the .8PE, the P-E, DD50s, DD60s, +90 Days, and all the HTs. The total line included averages of the values for Average Minimum Temperature, Average Maximum Temperature, and Average Day Length. The total line also included averages of the absolute highest value for the Absolute Maximum Temperature and the absolute lowest value for the Absolute Minimum Temperature for all the phenological periods in a given case.

Quality Control

This process was repeated for every single phenological period for every case in both Mature Group 4 and Mature Group 5. This was a very labor-intense and monotonous process, resulting in a set of 246 sets of data unique to each of the five phenological periods for each variety in each year. This procedure required sorting of almost 15,000 discrete sets of weather observations that had to be summed, averaged, ranked, or otherwise manipulated.

Errors inevitably occurred during this incredibly long and tedious process. However, quality control methods were invoked to assess the error magnitude and ensure the integrity of the data. 100 cases were chosen at random and spot-checked and errors were found in only 2% of the cases.

Statistical Methods

Data analyses for this project included descriptive statistics (averages, medians, standard deviations) using the raw data. These descriptive statistics were tabulated and graphed to gain an initial visual interpretation of possible links, and to discern any patterns in the raw data that could point out pertinent associations between the variables.

Relationships between weather and period lengths, period lengths and yield, and weather and yield were determined using Pearson's Correlation Analysis. The significance ($P = 0.05$ or $P = 0.01$) of each correlation was also determined.

Data Normalization

In studying the effects of weather on period length, it was necessary to address the problem of temporal autocorrelation. Longer period lengths would, by their very nature of being longer, have a better chance of experiencing a greater amount of one or more weather variables. In order to more accurately compare which weather variable might be influencing period length, it was necessary to normalize certain variables. Since a longer period length was known to be temporally autocorrelated with total precipitation, precipitation days, 0.8 PE, P-E, DD50s, DD60s, and +90 days, it was necessary to normalize each of these variables to make them suitable for comparative statistical analyses.

The data were normalized by dividing the summed variables by the number of days in the period. Creation of these normalized data effectively doubled the already immense volume of data. The normalized data were only used in the analyses involving weather and period length, not weather and yield or period length and yield. The normalized data were not used in conjunction with yield because it was thought that yield might have been influenced by the actual values of the raw data.

Analyses of Weather and Phenological Period Length

Analyses of the effect of weather on period lengths were completed first without considering yield. These first analyses were conducted in order to try to determine which weather variables have an impact upon phenological period lengths only—which conditions produced the highest yield were not analyzed until later in the study. As an initial attempt to understand and establish the relationship between phenological period length and weather, graphs were created to visually show associations of the weather variables with the growing time of each case.

The analyses of the effect of weather on period lengths did not include the HT variables. It was determined that the +90 days variable was a sufficient temperature threshold for the analysis of the effect of energy on period length and that further breakdown of high temperatures (HT 85--HT 98) was unnecessary. However, the HT variables were used in the analysis of weather versus yield in order to determine if there was a certain threshold temperature that influenced yield.

Descriptive Statistics and Graphs—Raw Data

Simple descriptive statistics of the values for the 12 variables used in the analysis of the effect of weather on period lengths (including the normalized data) for Mature Groups 4 and 5 were calculated and tabulated first (averages, maximum and minimum values, and standard deviations). For example, the average number of days, the average amount of precipitation, and the average amount of +90 days in the total growing period for the cases in Mature Group 4 was found. In addition to finding the averages of these variables for the total of all the phenological periods, the same descriptive statistics were found for each of the phenological periods and included in the tabulation.

From these summary statistics, four graphs were created. The summary statistics were graphed for each of the phenological periods, for both maturity groups, first by the raw data and then by derived variables. The graphs were based on an average planting date for each maturity group. The average planting date for Mature Group 4 was May 1, and the average planting date for Mature Group 5 was May 6. The raw data graph, divided up into phenological periods, included the total precipitation and evaporation, and the average maximum and minimum temperature and day length. The derived data graph, also divided up into the phenological periods, included the total DD50s, DD60s, and precipitation days, and the average absolute maximum and absolute minimum temperatures.

Two additional graphs were created from the summary statistics to show the cumulative curves for the average as compared to the longest and shortest total growth times for both groups 4 and 5. The average growing season was graphed along with the actual longest growing case and shortest growing case for each maturity group. In addition a “contrived high” and a “contrived low” were found that calculated the theoretical longest growing season and the theoretical shortest growing season. The “contrived high” was found by creating a theoretical case that had the longest plant to bloom period of all the cases, the longest bloom to podset, the longest podset to seedform, the longest seedform to fullseed, and longest fullseed to mature. The “contrived low” was found in this same manner except the shortest periods were used to create this theoretical case.

Described Statistics and Graphs—Normalized Data

After completion of the summary statistics, the problem with temporal autocorrelation became evident, and at this point in the study the data were normalized in order to try to rectify this source of bias and error. Comparative weekly averages were compiled of both the raw data and the normalized data in order to try to determine if there were any weather similarities between cases that had short or long phenological periods. Each phenological period was sorted by the number of days in that period. Next the phenological periods were sorted by determining which cases had the very shortest periods (which cases finished that phase of growth earliest and around the same Julian calendar day). These cases were grouped together and the average of all their associated weather and bean data was taken to create a representation of the "Earliest" group. Subsequent cases were grouped and averaged together by those that finished one week after the "Earliest" group (+1 weeks), then two weeks after (+2 weeks), and so on until the end of the phenological period. All of the phenological periods of both Mature Groups 4 and 5 were divided up in this manner.

In addition to the individual phenological periods, the cases were sorted by the total number of days in the growing period. These "total" cases, like the phenological periods, were broken up by determining which of the cases had the shortest total growing periods, averaging their associated weather and bean data and calling it the "Earliest" group. Subsequent cases again were grouped together by those that finished one week after the "Earliest" group (+1 weeks) and then two weeks (+2 weeks), until the end of the total growing period.

These comparative weekly averages were used to create graphs in order to investigate the relationships between the length of phenological periods and weather. For example, for Mature Group 4, the "Earliest" P-B period and the longest (+3 weeks) P-B period were graphed based on the number of days in the periods. Then the average number of normalized +90 days associated with the shortest P-B period and the longest P-B period were added to the graph. This same procedure was followed for all the periods for both Mature Group 4 and Mature Group 5. Two additional graphs were created from the comparative weekly averages following this same procedure but using the normalized total precipitation as the weather variable.

Correlation Analyses and Graphs

In addition to descriptive statistics, Pearson’s Correlation Analysis was used to determine the strength of the relationships between the different weather variables and period length. Correlation analyses were performed on both the raw and the normalized data. The 12 weather variables (HTs were not included) were grouped into energy-related (0.8PE, DD50s, DD60s, AbsMinT, AbsMaxT, +90 Days, AvgMinT, AvgMaxT, and AvgDayLn), water-related (totP, Pdays), and combined energy-water-related (P-E) categories. The purpose of this grouping was to isolate any effects of energy, as compared to effects of moisture, on the phenological period lengths. This was accomplished through correlation analysis, in which each weather variable was correlated with its corresponding period length. The results of the correlations were tabulated in order to show those variables that exert an influence over the period lengths of soybeans.

Analyses of Weather and Yield and Phenological Period Length and Yield

Descriptive Statistics

After completing the analyses on weather and period length, the effect of weather on soybean yield was studied. As with weather and period length, descriptive statistics were calculated first. All of the cases in Mature Group 4 and

Mature Group 5 were sorted by phenological period. Within each phenological period the cases were sorted by yield. Four categories were created to rank the cases by yield: less than 20.0 bushels per acre; 20.1-30.0 bushels per acre; 30.1-40.0 bushels per acre; and over 40.1 bushels per acre. After ranking the cases, the averages, standard deviations, and medians of all the weather variables and number of days in the period were found for each of the four yield categories. After calculating the values for all of the phenological periods, a "totals" chart was created. The totals chart had the four categories of yield with each of the phenological periods that corresponded to the yield category. A "totals" line was created that summed or averaged all of the weather variables for the entire growing season for a given yield category.

In addition to ranking all the cases by yield and finding the average weather associated with the yield levels, the highest and lowest yield cases were found for each of the maturity groups. The highest and lowest cases for each maturity group were made into a chart that contained a "totals" line that contained the averages, absolute values, and summed totals of all the weather variables.

Correlation Analyses and Graphs

In addition to descriptive statistics, correlation analyses and significance tests were conducted to try to determine which of the variables were strongly related to soybean yield. The spreadsheets containing the soybean and weather data were imported into a statistics software program, Statistical Package for the Social

Sciences (SPSS). Once the data were entered into SPSS, Pearson's Correlation Analyses were performed in order to determine how strongly related a given variable was to soybean yield. Each phenological period in each maturity group was tested separately, in addition to testing each maturity group as a whole. Along with the correlation coefficients, the significance of the relationships was determined. After completion of the correlation analyses and significance tests, a table was constructed for each of the maturity groups that listed those variables that were found to be either highly significant (at the 0.01 level) or significant (at the 0.05 level) by total and by each phenological period. After tabulating the results of the correlation analyses and significance tests, scatter plots of those variables that were determined to be important in soybean yield were made in order to visually assess pertinent relationships.

Assumptions

This study employed several assumptions, which may or may not affect the outcome of the research. First, data isolated within each of the 246 periods were considered discrete—that is, no antecedent conditions were considered. For example, a heavy rain occurring at the very end of the plant to bloom period is not considered in this study to have an effect on the soybean in the bloom to podset period, although in actuality the effect of a heavy rainfall at the end of a phenological period probably would impact the succeeding period. Second, the only weather variables considered were the 25 described above. There may be other weather variables and environmental conditions such as insect infestations that were not considered which may be important in determining period length or yield. Third, possible effects of physiological responses such as compensatory growth were not considered. And finally, the weather data were taken from a single point, whereas bean data were taken over large areas.

CHAPTER IV

RESULTS AND DISCUSSION

Analyses of Weather and Phenological Period Length

Descriptive Statistics and Graphs

The analysis of the relationship between phenological period length and weather began with descriptive statistics. Figure 3 shows Case #113 of Maturity Group 4 beans that was used as an example of the process of establishing the association between weather variables and discrete phenological periods by Julian calendar days. This graph shows the entire growing season for that case broken up by phenological periods. Five weather variables were associated with the growing season—total precipitation, absolute maximum temperature, absolute minimum temperature, average day length, and evaporation. In this case the crop was planted on April 28, 2000. The plant to bloom period lasted 34 days, during which 6.98" of rain fell, 0.8PE totaled 6.94", daylength averaged 13.7 hours, average maximum and minimum temperatures were 84.5°F and 64.7°F, respectively. In comparison, the P-S period began on June 26 and lasted only 16 days. Total precipitation was 1.99", 0.8PE was 3.02", daylength averaged 14.2 hours, and maximum and minimum temperatures averaged 90.5°F and 72.1°F, respectively. It was apparent that cumulative values, such as total precipitation and 0.8PE, were integrally linked to period length. In other words, if period length were longer

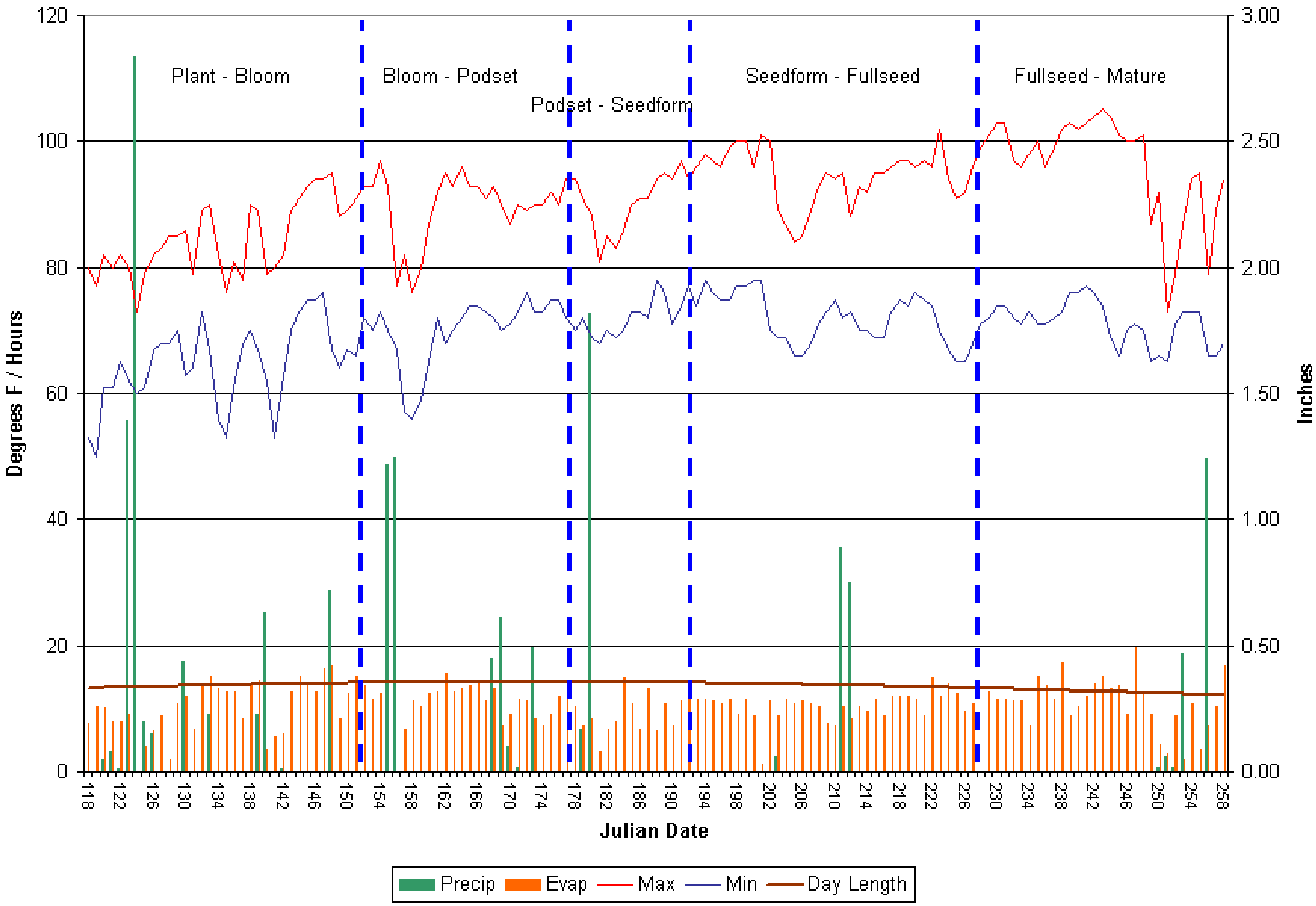


Figure 3: Mature Group 4 Case # 113 Graph

these totals would invariably be larger. This temporal autocorrelation led to the need for the normalization of the data.

From the analyses linking weather data to phenological periods, several observations became clear. First, daylength changed very little during the entire growing season. It ranged from 12.7 hours to 14.2 hours. Second, it is clear from Figure 3 that the genuine values of the weather variables were not as discrete as they were treated. For example, antecedent conditions of rainfall, particularly, could influence available moisture during the period under consideration. Third, using the seedform to fullseed period as an example, it can be seen that the single value (total precipitation) representing the effect of precipitation over the total period length actually occurred on only two days in the middle of the 37-day period.

Tables 1 and 2 specify the simple descriptive statistics for each of the phenological period lengths (as well as the total averages) and of the 12 associated weather variables in both Maturity Groups 4 and 5 (total of 246 cases). Figures 4 and 5 graphically show *total* period values (bars) of precipitation and evaporation, and *average* values (lines) of maximum and minimum temperatures and daylength. Average phenological period lengths are separated by dashed vertical lines for comparison. The impact of the autocorrelation problem is evident, as longer period lengths (for example, the plant to bloom period and the seedform to fullseed period) tend to show larger summed values of the continuous variables such as 0.8PE. For example, average plant to bloom periods varied between maturity groups from 43 to 54 days, a 25% difference in length, yet 0.8PE increased 33% (9” to 12”) during

Period Type		# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
P-B	average	43.24	6.27	12.91	9.08	-2.80	1057.01	634.09	64.77	84.85	49.15	95.02	13.77	10.98
	min	30.00	1.07	3.00	6.53	-6.81	780.00	351.00	54.81	75.13	36.00	90.00	13.13	0.00
	max	70.00	13.22	24.00	13.28	2.13	1480.50	1000.00	75.17	94.48	69.00	101.00	14.19	33.00
	std	8.75	2.28	4.17	1.65	2.31	217.31	173.78	4.58	4.18	7.73	2.50	0.26	8.36
B-P	average	22.35	3.36	7.23	4.83	-1.47	705.52	476.50	71.14	90.12	62.75	96.42	14.12	13.11
	min	7.00	0.00	0.00	1.49	-5.75	252.00	182.00	65.39	83.94	53.00	90.00	13.57	0.00
	max	37.00	12.19	19.00	12.73	6.34	1944.00	1384.00	76.24	96.33	72.00	101.00	14.22	45.00
	std	5.34	2.25	3.24	1.47	1.81	226.81	164.81	2.81	2.49	5.63	2.24	0.13	6.89
P-S	average	17.84	2.41	4.73	3.65	-1.24	572.31	393.90	72.66	91.64	67.35	97.15	13.96	11.86
	min	10.00	0.00	0.00	1.58	-5.32	308.50	198.50	65.31	84.69	57.00	93.00	13.16	2.00
	max	32.00	12.19	16.00	6.18	7.34	1004.00	714.00	76.52	96.87	73.00	101.00	14.21	22.00
	std	4.24	2.52	3.47	1.02	2.34	135.40	95.74	1.90	2.49	3.27	2.02	0.28	4.54
S-F	average	28.72	2.24	5.96	5.89	-3.65	926.31	639.50	71.55	92.82	64.42	99.63	13.47	20.97
	min	16.00	0.07	1.00	2.58	-7.02	410.00	250.00	63.33	83.86	54.00	91.00	12.63	1.00
	max	42.00	5.42	16.00	9.15	0.49	1443.50	1023.50	75.26	96.74	73.00	104.00	14.07	36.00
	std	5.38	1.59	3.81	1.16	1.83	198.24	147.02	2.30	2.64	3.98	2.73	0.36	6.99
F-M	average	20.52	1.31	4.04	4.26	-2.94	642.77	426.58	67.49	91.32	59.59	98.50	12.72	13.80
	min	7.00	0.00	0.00	1.35	-7.34	215.00	135.00	60.69	84.20	45.00	90.00	11.98	0.00
	max	38.00	4.55	11.00	8.38	2.35	1253.00	863.00	72.97	99.67	69.00	105.00	13.87	30.00
	std	6.50	1.14	2.73	1.49	1.85	232.18	169.69	3.25	3.68	5.47	3.72	0.35	7.17
Total	average	132.67	15.51	34.65	27.56	-11.94	3871.67	2555.87	69.50	90.10	47.65	100.78	13.75	70.36
	min	98.00	8.78	17.00	19.11	-18.94	2818.50	1798.50	66.90	85.44	36.00	97.00	13.10	29.00
	max	161.00	22.56	51.00	32.42	-6.09	4346.50	2906.50	72.61	92.54	62.00	105.00	13.36	87.00
	std	12.50	3.54	7.49	2.62	2.83	304.75	214.89	1.23	1.62	5.80	2.70	1.59	12.62

Table 2: Mature 5 Summary Statistics

Period Type		# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
P-B	average	54.34	7.38	16.20	11.53	-4.15	1425.03	890.11	66.71	86.44	50.46	96.09	13.93	16.92
	max	73.00	13.22	24.00	14.41	2.64	1669.50	1162.50	75.00	93.44	69.00	101.00	14.16	38.00
	min	37.00	3.21	5.00	7.45	-10.71	964.50	487.00	57.69	77.21	36.00	90.00	13.35	0.00
	stdev	7.16	2.62	4.03	1.26	2.30	148.41	132.03	3.56	3.18	7.25	1.84	0.19	7.94
B-P	average	22.59	2.97	7.14	4.79	-1.82	723.11	497.02	72.40	91.43	65.70	97.02	14.04	14.97
	max	32.00	11.57	15.00	7.88	6.55	1187.00	857.00	76.48	96.75	73.00	103.00	14.21	30.00
	min	13.00	0.24	1.00	2.22	-6.81	398.50	259.50	67.59	86.29	57.00	92.00	13.51	3.00
	stdev	4.83	2.68	3.09	1.24	2.61	167.81	121.73	1.97	2.13	3.96	2.21	0.17	5.57
P-S	average	15.72	2.06	4.67	3.10	-1.04	501.47	344.40	72.18	91.48	67.16	96.86	13.69	10.31
	max	25.00	11.56	13.00	5.82	7.93	835.00	585.00	76.22	97.72	73.00	101.00	14.16	24.00
	min	9.00	0.00	0.00	1.30	-4.84	195.50	105.50	61.56	81.89	57.00	85.00	13.10	0.00
	stdev	3.51	2.42	3.04	0.90	2.51	123.14	90.22	2.31	3.03	3.77	2.97	0.26	5.16
S-F	average	29.52	2.10	6.74	5.85	-3.75	902.49	607.11	69.52	91.34	60.75	98.38	13.06	18.86
	max	45.00	7.13	21.00	9.10	0.89	1340.00	940.00	74.36	96.33	73.00	104.00	13.78	38.00
	min	12.00	0.23	1.00	2.46	-8.24	369.00	233.00	63.80	84.20	51.00	91.00	12.53	1.00
	stdev	6.52	1.65	3.84	1.55	2.38	224.75	164.03	2.37	3.07	4.52	3.41	0.27	8.96
F-M	average	18.06	1.92	4.34	3.39	-1.47	477.32	285.40	62.65	87.09	53.29	94.86	12.23	6.57
	max	40.00	5.01	11.00	9.26	2.19	1094.00	684.00	69.27	97.00	67.00	100.00	12.90	19.00
	min	4.00	0.00	0.00	0.83	-4.59	164.50	114.50	55.55	80.33	42.00	89.00	11.79	0.00
	stdev	6.30	1.39	2.22	1.24	1.43	169.47	108.64	3.05	2.95	5.65	3.05	0.23	4.34
Total	average	140.23	16.43	39.08	28.65	-12.22	4029.42	2624.04	68.69	89.56	47.11	99.52	13.39	67.64
	max	167.00	22.91	51.00	34.88	-2.65	4816.00	3182.00	71.30	92.97	56.00	104.00	13.72	99.00
	min	108.00	8.23	25.00	19.88	-20.57	2875.00	1785.00	65.33	85.44	36.00	95.00	13.05	27.00
	stdev	12.95	3.55	6.32	3.21	3.90	342.97	247.33	1.05	1.62	5.07	2.41	0.15	17.97

those extra 11 days. These tables show that total precipitation decreases through the growing season, while 0.8PE was consistently higher than total precipitation. The pattern of temperatures and daylength is also evident. It is noteworthy that daylength showed little variation throughout all stages of the crop.

Figures 4 and 5 show similar results for the derived weather variables. Once again the totaled values are shown as bars, the averaged values are shown as lines. Impacts of autocorrelation are again clear in total values such as DD50s. It should be noted that the +90 Days derived variable is not commonly seen or used but was included in this study based on the experience of the USDA-ARS plant specialists (Heatherly 2002). As compared to DD50s and DD60s, +90 Days seem to be more closely connected to time of year than to period length (temporal autocorrelation).

Figures 6 and 7 show similar results for the derived weather variables. Once again the totaled values are shown as bars, the averaged values are shown as lines. Impacts of autocorrelation are again clear in total values such as DD50s. It should be noted that the +90 Days derived variables is not commonly seen or used, but was included in this study based on the experience of the USDA-ARS plant specialists (Heatherly 2002). As compared to DD50s and DD60s, +90 Days seem to be more closely connected to time of year than to period length (temporal autocorrelation).

Figures 8 and 9 show cumulative curves for the average as compared to the longest and shortest total growth times for both groups 4 and 5. These figures illustrate that there is considerable range between the high and low extremes of total growth times. This variation may be attributable to environmental factors such as

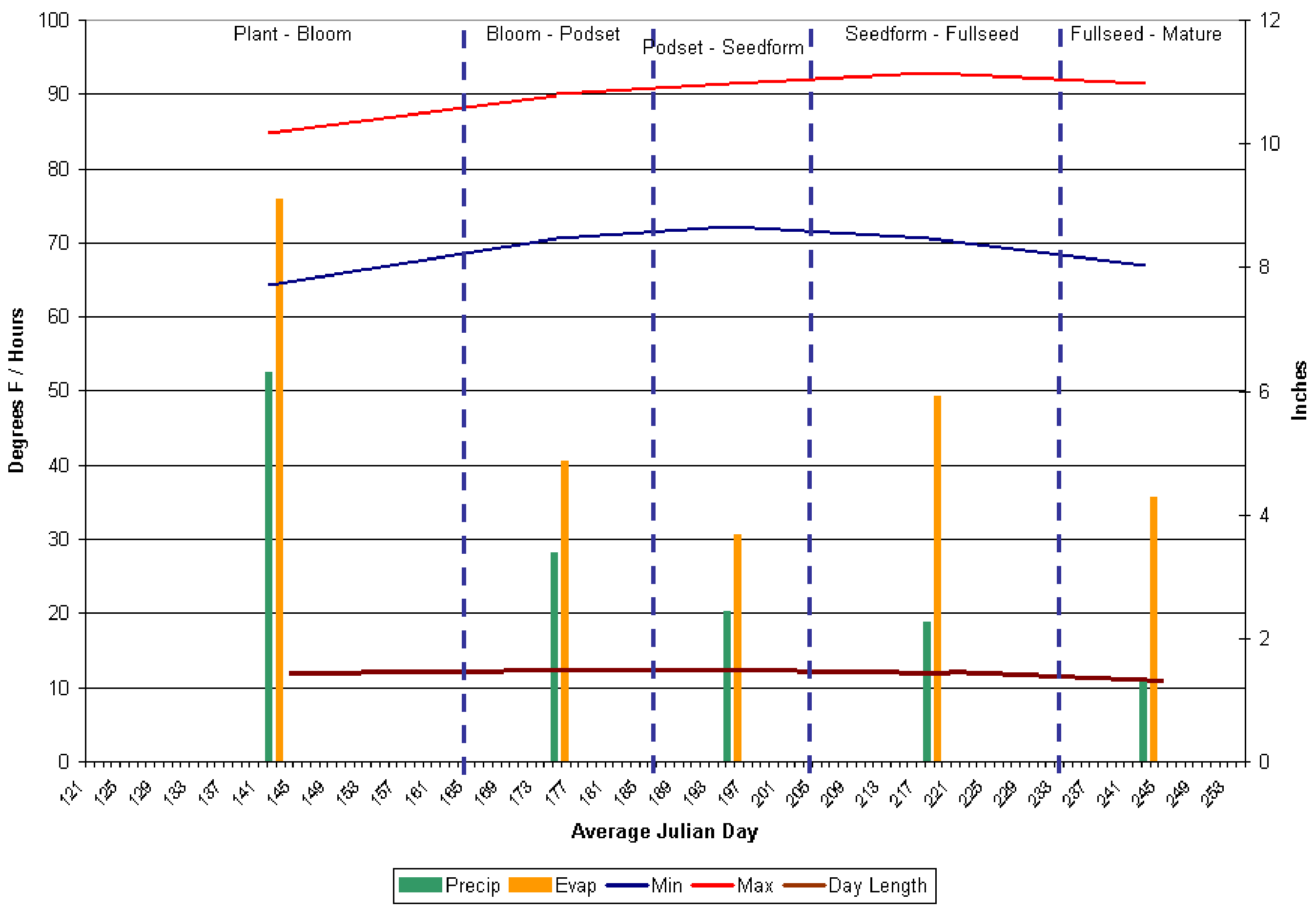


Figure 4: Mature Group 4 Measured Variables

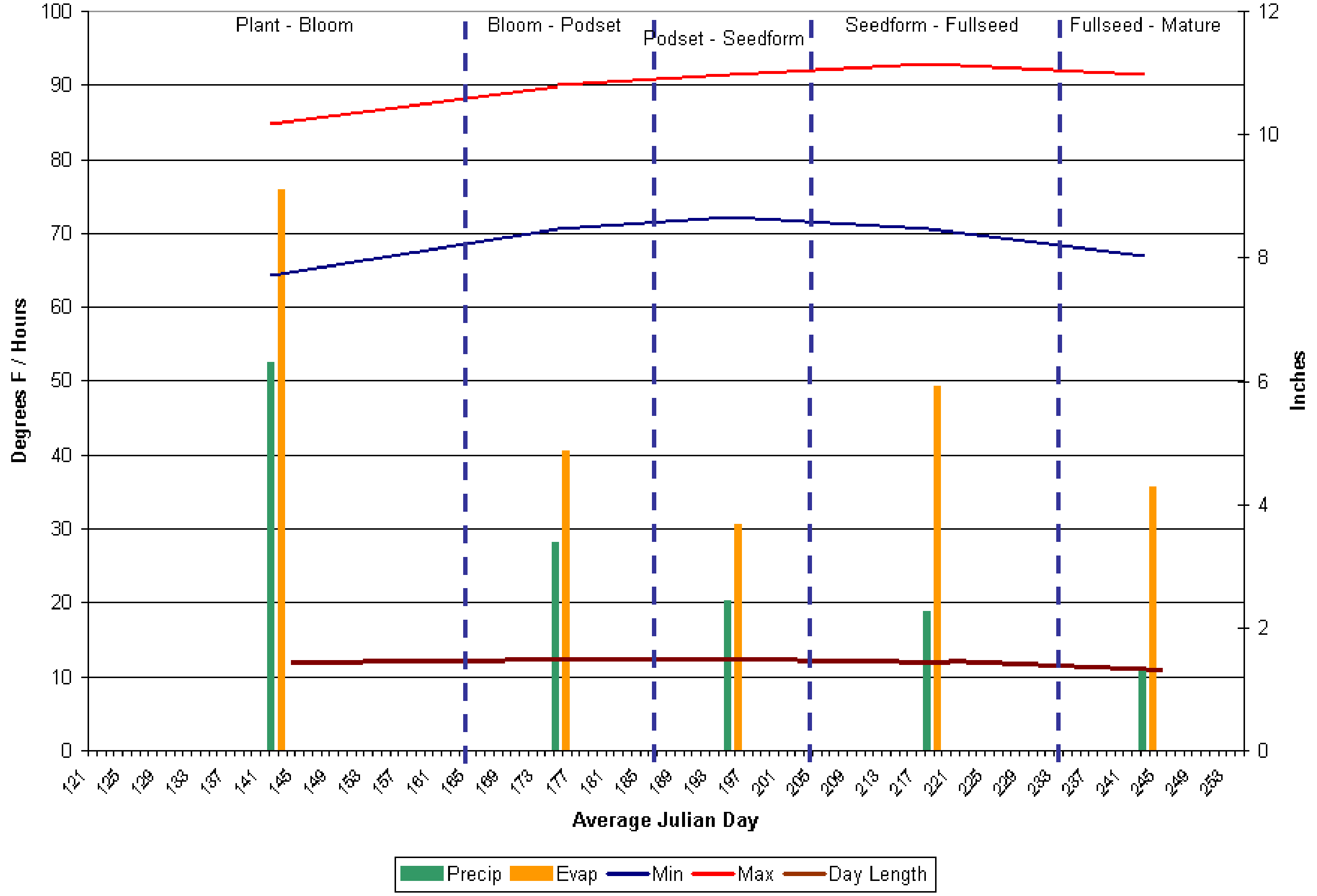


Figure 5: Mature Group 4 Derived Variables

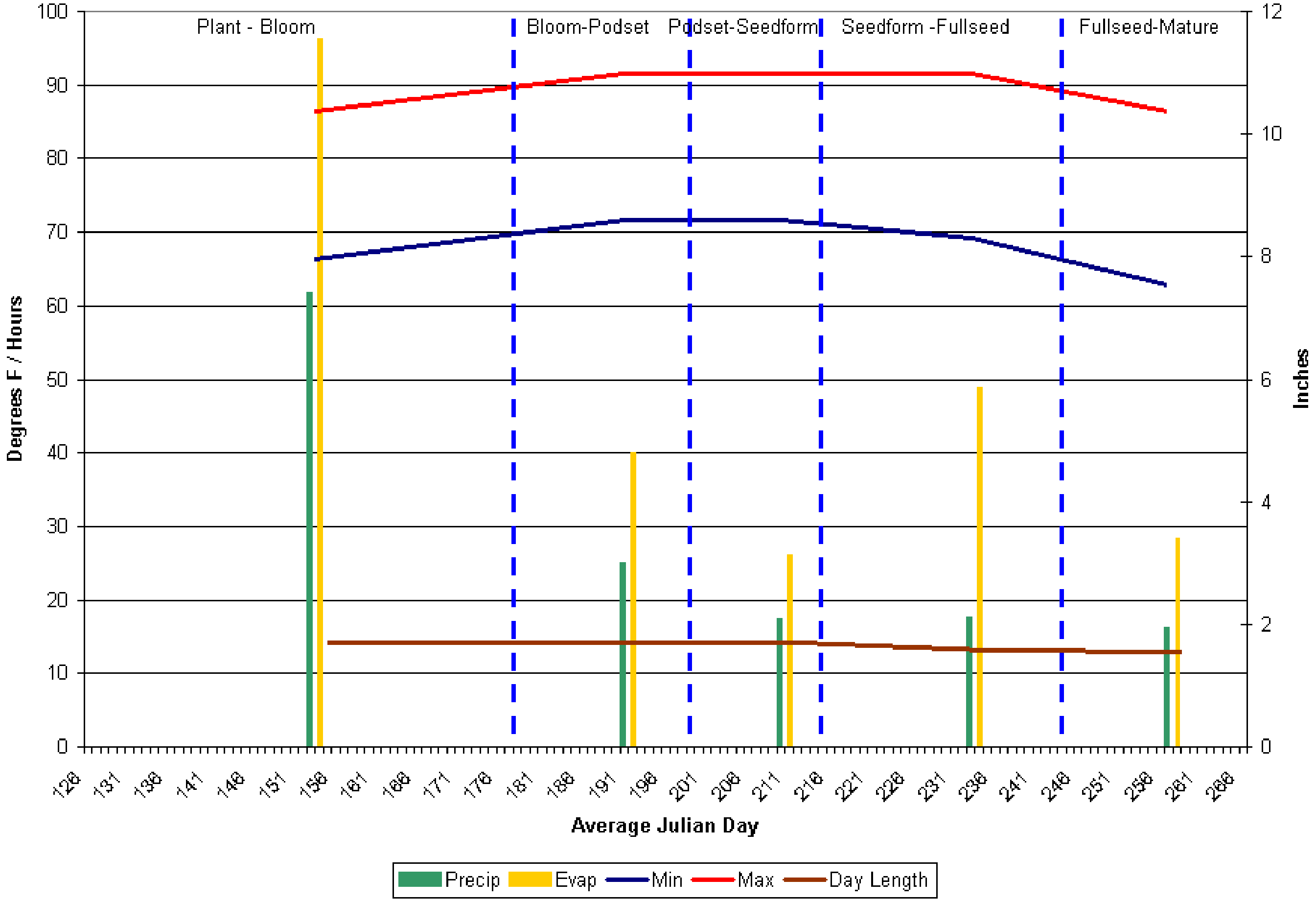


Figure 6: Mature Group 5 Measured Variables

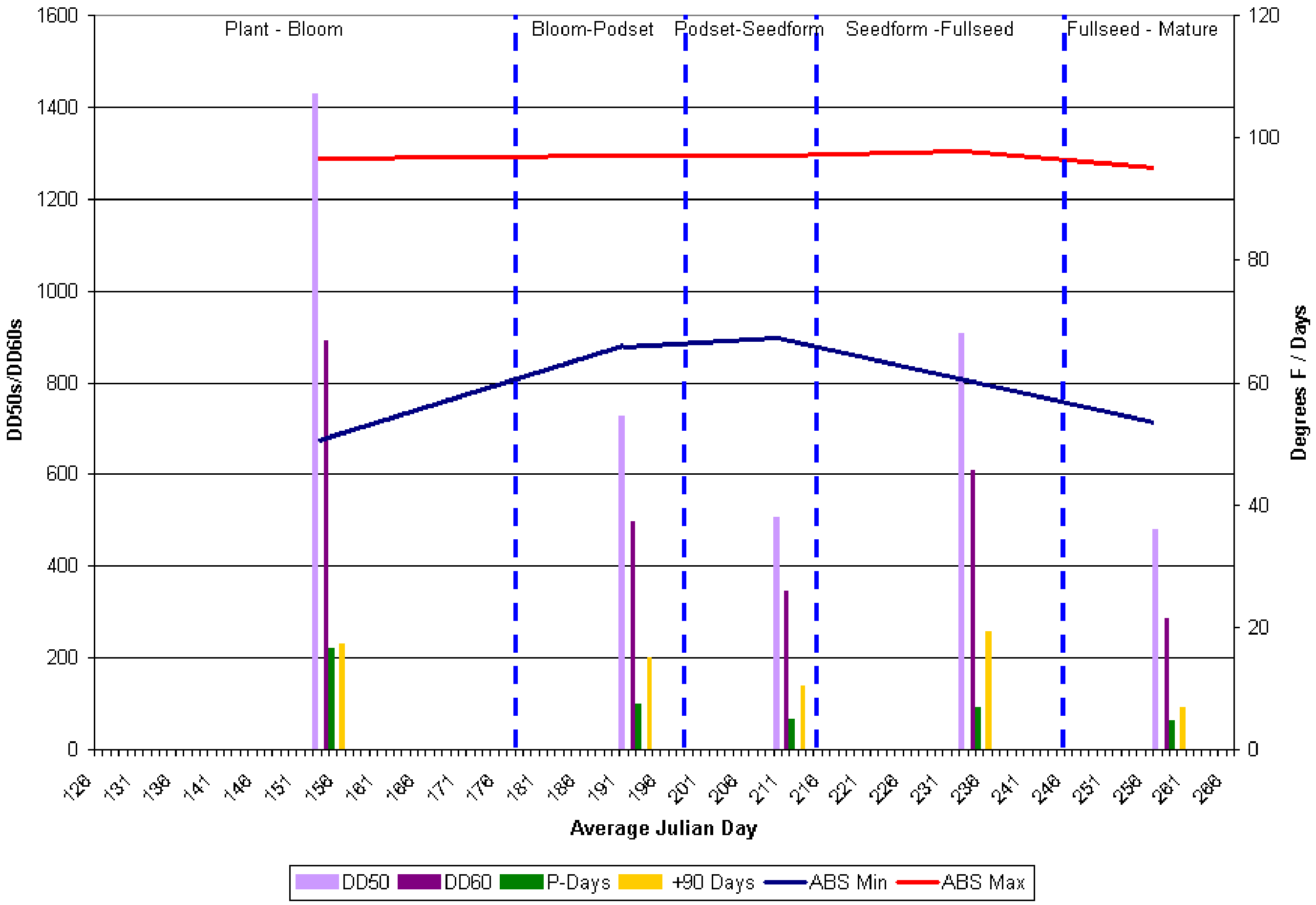


Figure 7: Mature Group 5 Derived Variables

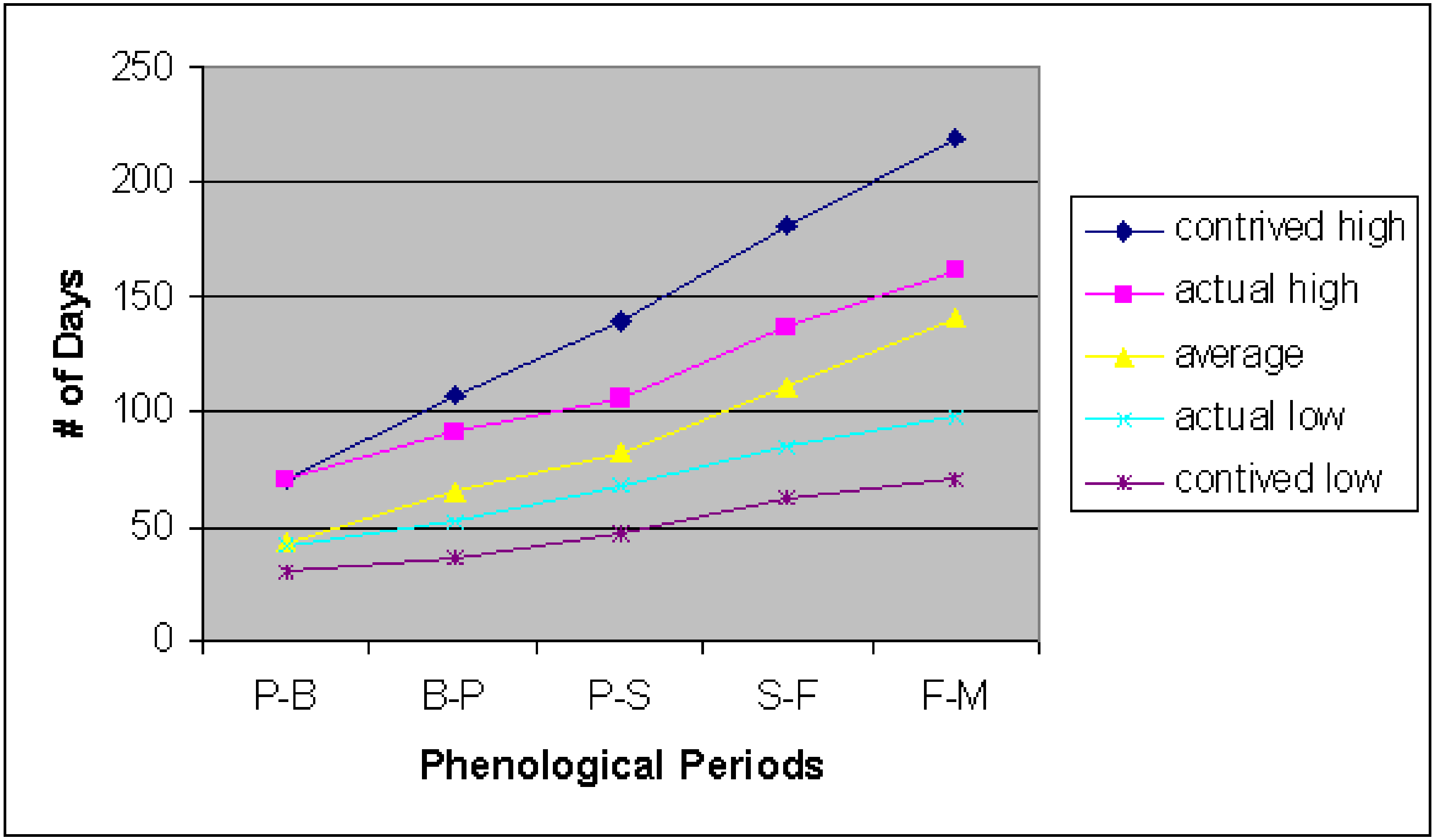


Figure 8: Cumulative Period Lengths for Selected Mature Group 4 Scenarios

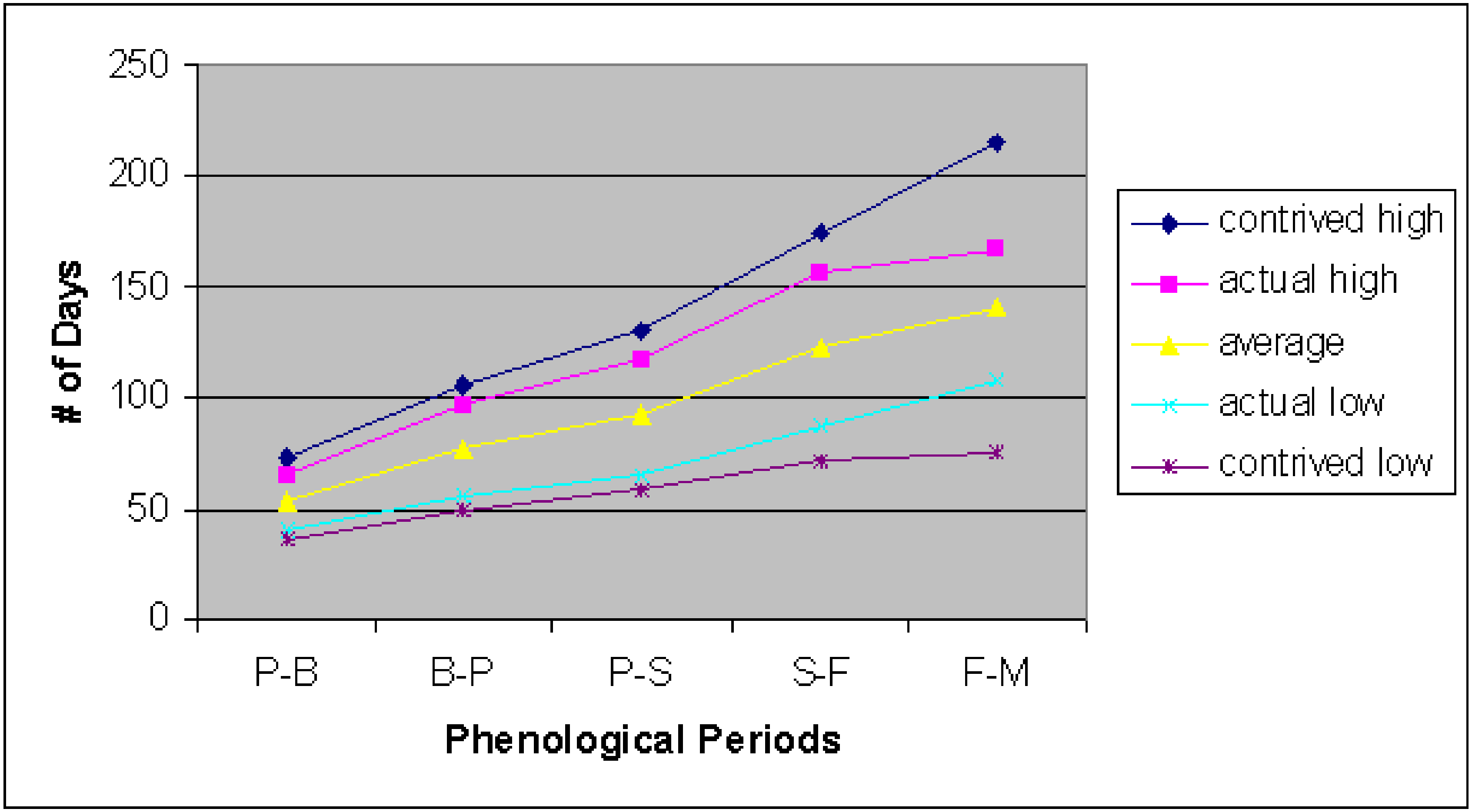


Figure 9: Cumulative Period Lengths for Selected Mature Group 5 Scenarios

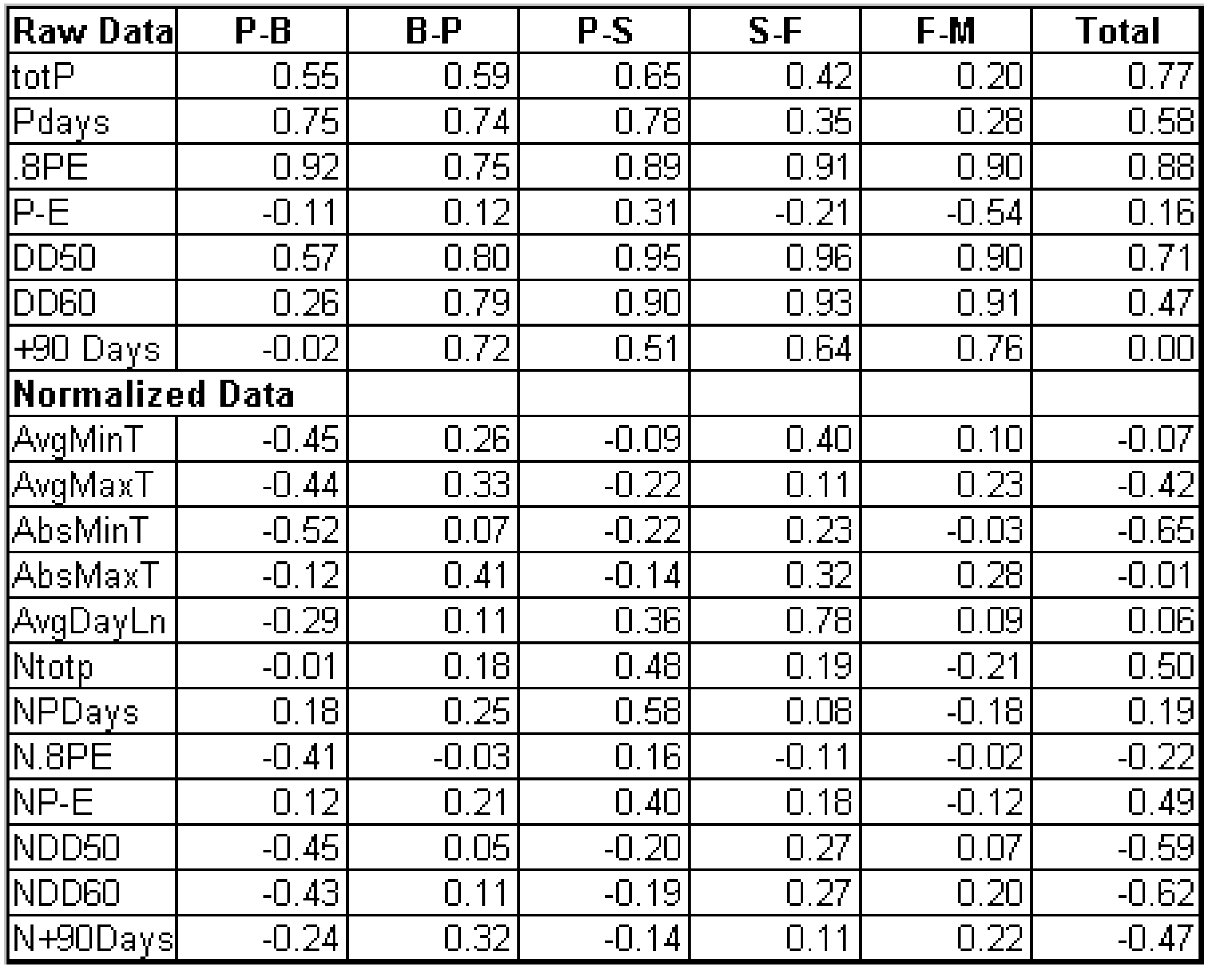
weather. The times for maturity of the two groups ranged from a low of around 100 days to a high of 170 days. The average was approximately 140 days for both Maturity Groups 4 and 5.

Correlation Analyses

Results of the correlation analyses for both raw and normalized data for Maturity Groups 4 and 5 are shown in Tables 3 and 4. Since temporal autocorrelation was recognized as a source of bias, only results of correlations of the normalized data were carried further. Tables 5 and 6 summarize those findings for each of the maturity groups, sorted by the energy, moisture, and combined energy-moisture groups of variables. Color-coding shows which variables of each group exhibited strongest correlation in each phenological period. The energy group of variables consistently dominated as an indicator of period lengths—water showed little effect. From these results, the normalized total precipitation variable (NtotP) was selected to represent the moisture group and the normalized days above 90^{o}F (N+90Days) variable was selected to represent the energy group for further analysis.

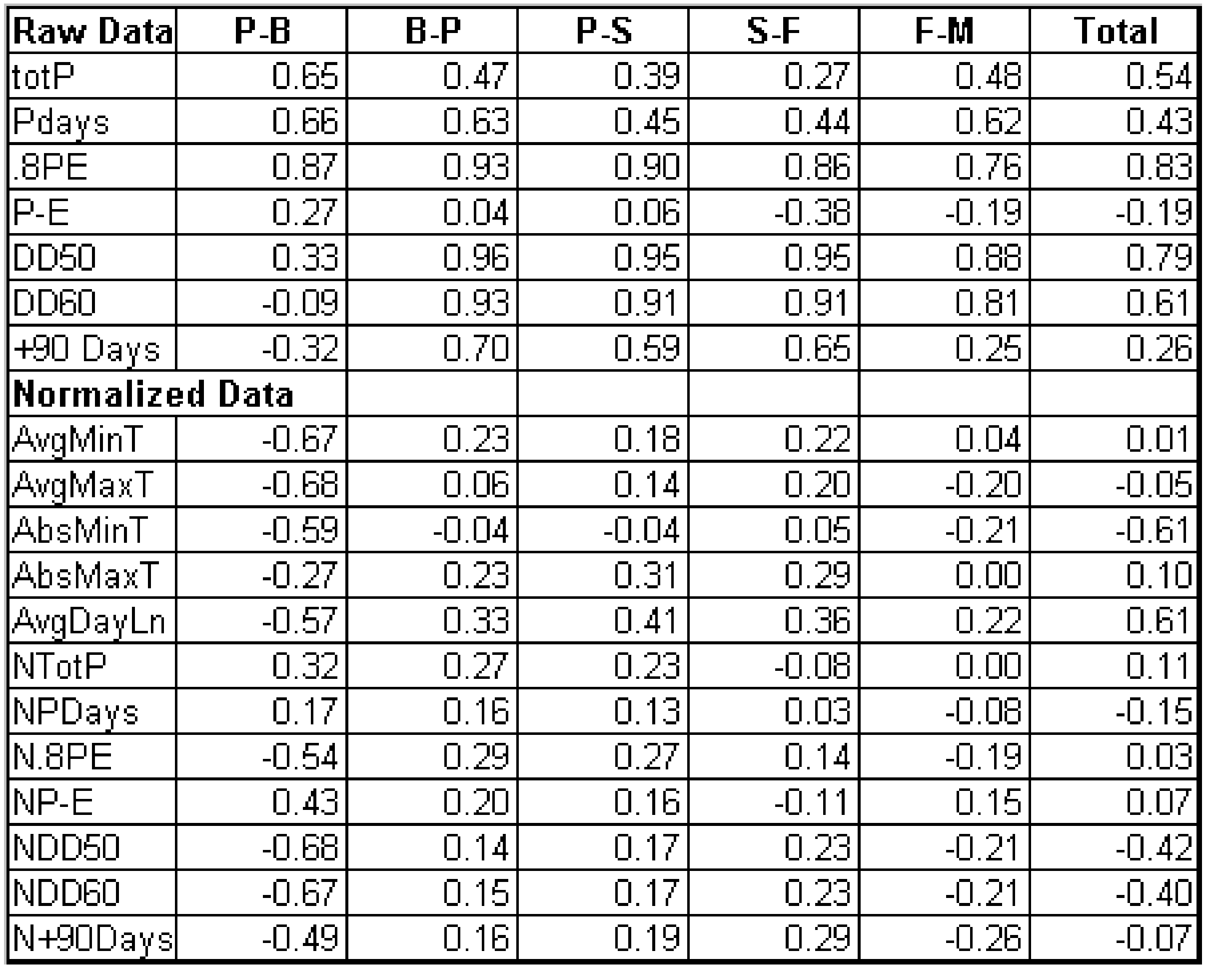
Figures 10 and 11 show the graphs of the comparative weekly averages that were used to create graphs in order to illustrate the relationships between the length of phenological periods and weather. Figures 10 and 11 show the extreme short and extreme long cases, as impacted by moisture, in both groups of beans. The relationship between normalized total precipitation and period length is shown for each phenological period. The link does not appear to be strong or consistent within

Table 3: Results of Correlation Analyses for Raw and Normalized Data for Mature Group 4



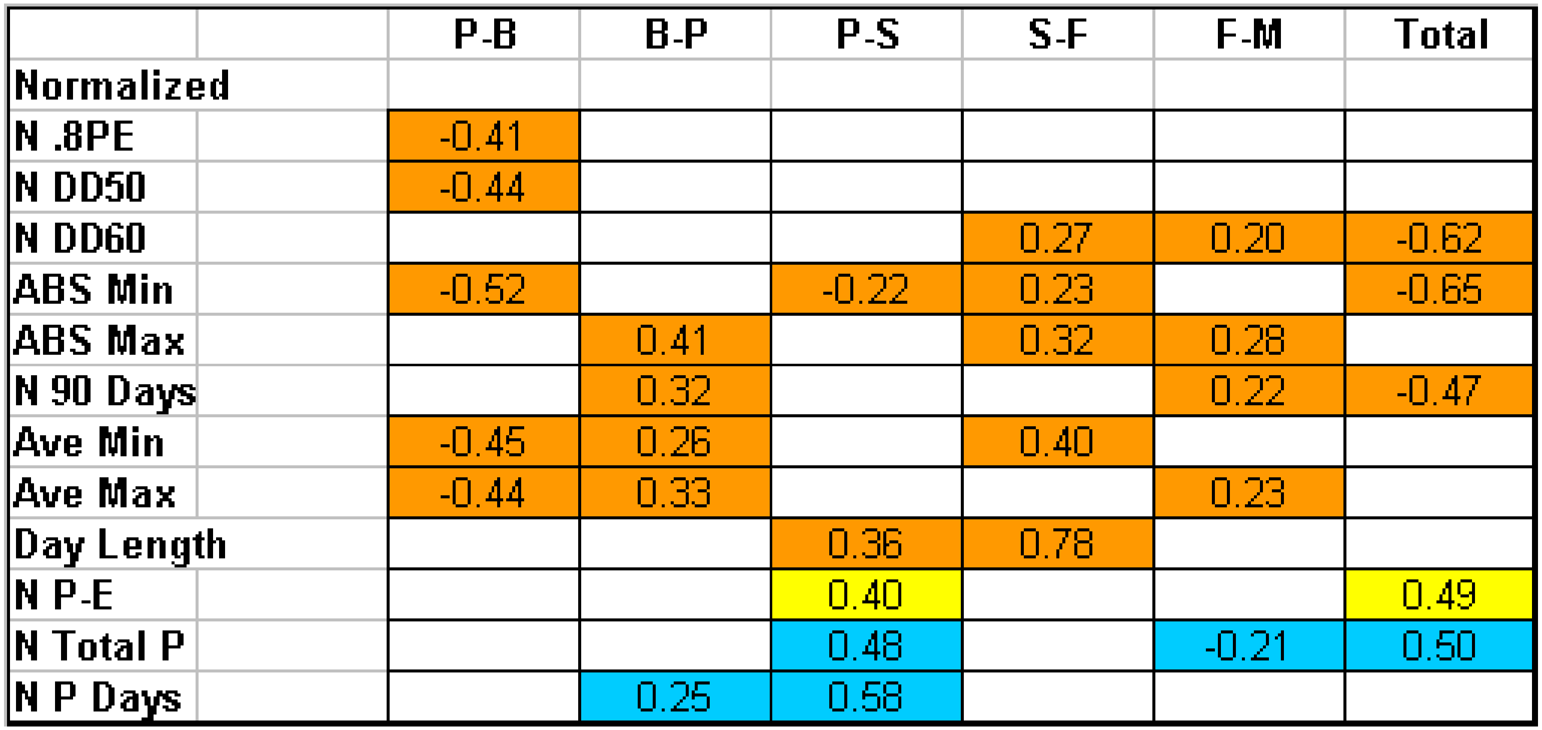
Raw Data	P-B	B-P	P-S	S-F	F-M	Total
totP	0.55	0.59	0.65	0.42	0.20	0.77
Pdays	0.75	0.74	0.78	0.35	0.28	0.58
.8PE	0.92	0.75	0.89	0.91	0.90	0.88
P-E	-0.11	0.12	0.31	-0.21	-0.54	0.16
DD50	0.57	0.80	0.95	0.96	0.90	0.71
DD60	0.26	0.79	0.90	0.93	0.91	0.47
+90 Days	-0.02	0.72	0.51	0.64	0.76	0.00
Normalized Data						
AvgMinT	-0.45	0.26	-0.09	0.40	0.10	-0.07
AvgMaxT	-0.44	0.33	-0.22	0.11	0.23	-0.42
AbsMinT	-0.52	0.07	-0.22	0.23	-0.03	-0.65
AbsMaxT	-0.12	0.41	-0.14	0.32	0.28	-0.01
AvgDayLn	-0.29	0.11	0.36	0.78	0.09	0.06
Ntotp	-0.01	0.18	0.48	0.19	-0.21	0.50
NPDays	0.18	0.25	0.58	0.08	-0.18	0.19
N.8PE	-0.41	-0.03	0.16	-0.11	-0.02	-0.22
NP-E	0.12	0.21	0.40	0.18	-0.12	0.49
NDD50	-0.45	0.05	-0.20	0.27	0.07	-0.59
NDD60	-0.43	0.11	-0.19	0.27	0.20	-0.62
N+90Days	-0.24	0.32	-0.14	0.11	0.22	-0.47

Table 5: Results of Correlation Analyses for Raw and Normalized Data for Mature Group 5



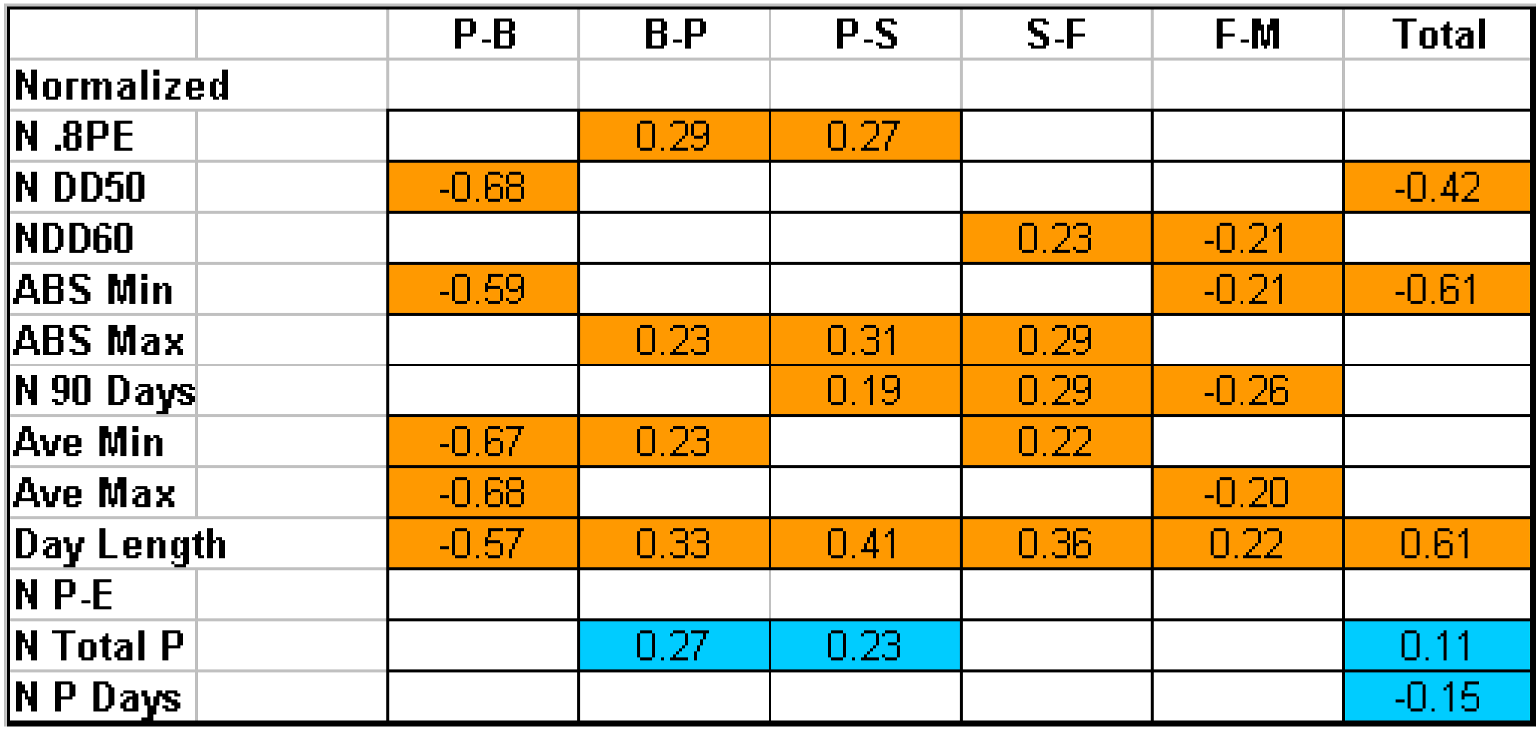
Raw Data	P-B	B-P	P-S	S-F	F-M	Total
totP	0.65	0.47	0.39	0.27	0.48	0.54
Pdays	0.66	0.63	0.45	0.44	0.62	0.43
.8PE	0.87	0.93	0.90	0.86	0.76	0.83
P-E	0.27	0.04	0.06	-0.38	-0.19	-0.19
DD50	0.33	0.96	0.95	0.95	0.88	0.79
DD60	-0.09	0.93	0.91	0.91	0.81	0.61
+90 Days	-0.32	0.70	0.59	0.65	0.25	0.26
Normalized Data						
AvgMinT	-0.67	0.23	0.18	0.22	0.04	0.01
AvgMaxT	-0.68	0.06	0.14	0.20	-0.20	-0.05
AbsMinT	-0.59	-0.04	-0.04	0.05	-0.21	-0.61
AbsMaxT	-0.27	0.23	0.31	0.29	0.00	0.10
AvgDayLn	-0.57	0.33	0.41	0.36	0.22	0.61
NTotP	0.32	0.27	0.23	-0.08	0.00	0.11
NPDays	0.17	0.16	0.13	0.03	-0.08	-0.15
N.8PE	-0.54	0.29	0.27	0.14	-0.19	0.03
NP-E	0.43	0.20	0.16	-0.11	0.15	0.07
NDD50	-0.68	0.14	0.17	0.23	-0.21	-0.42
NDD60	-0.67	0.15	0.17	0.23	-0.21	-0.40
N+90Days	-0.49	0.16	0.19	0.29	-0.26	-0.07

Table 5: Summarized Results of Correlation Analyses for Mature Group 4



	P-B	B-P	P-S	S-F	F-M	Total
Normalized						
N .8PE	-0.41					
N DD50	-0.44					
N DD60				0.27	0.20	-0.62
ABS Min	-0.52		-0.22	0.23		-0.65
ABS Max		0.41		0.32	0.28	
N 90 Days		0.32			0.22	-0.47
Ave Min	-0.45	0.26		0.40		
Ave Max	-0.44	0.33			0.23	
Day Length			0.36	0.78		
N P-E			0.40			0.49
N Total P			0.48		-0.21	0.50
N P Days		0.25	0.58			

Table 6: Summarized Results of Correlation Analyses for Mature Group 5



	P-B	B-P	P-S	S-F	F-M	Total
Normalized						
N .8PE		0.29	0.27			
N DD50	-0.68					-0.42
NDD60				0.23	-0.21	
ABS Min	-0.59				-0.21	-0.61
ABS Max		0.23	0.31	0.29		
N 90 Days			0.19	0.29	-0.26	
Ave Min	-0.67	0.23		0.22		
Ave Max	-0.68				-0.20	
Day Length	-0.57	0.33	0.41	0.36	0.22	0.61
N P-E						
N Total P		0.27	0.23			0.11
N P Days						-0.15

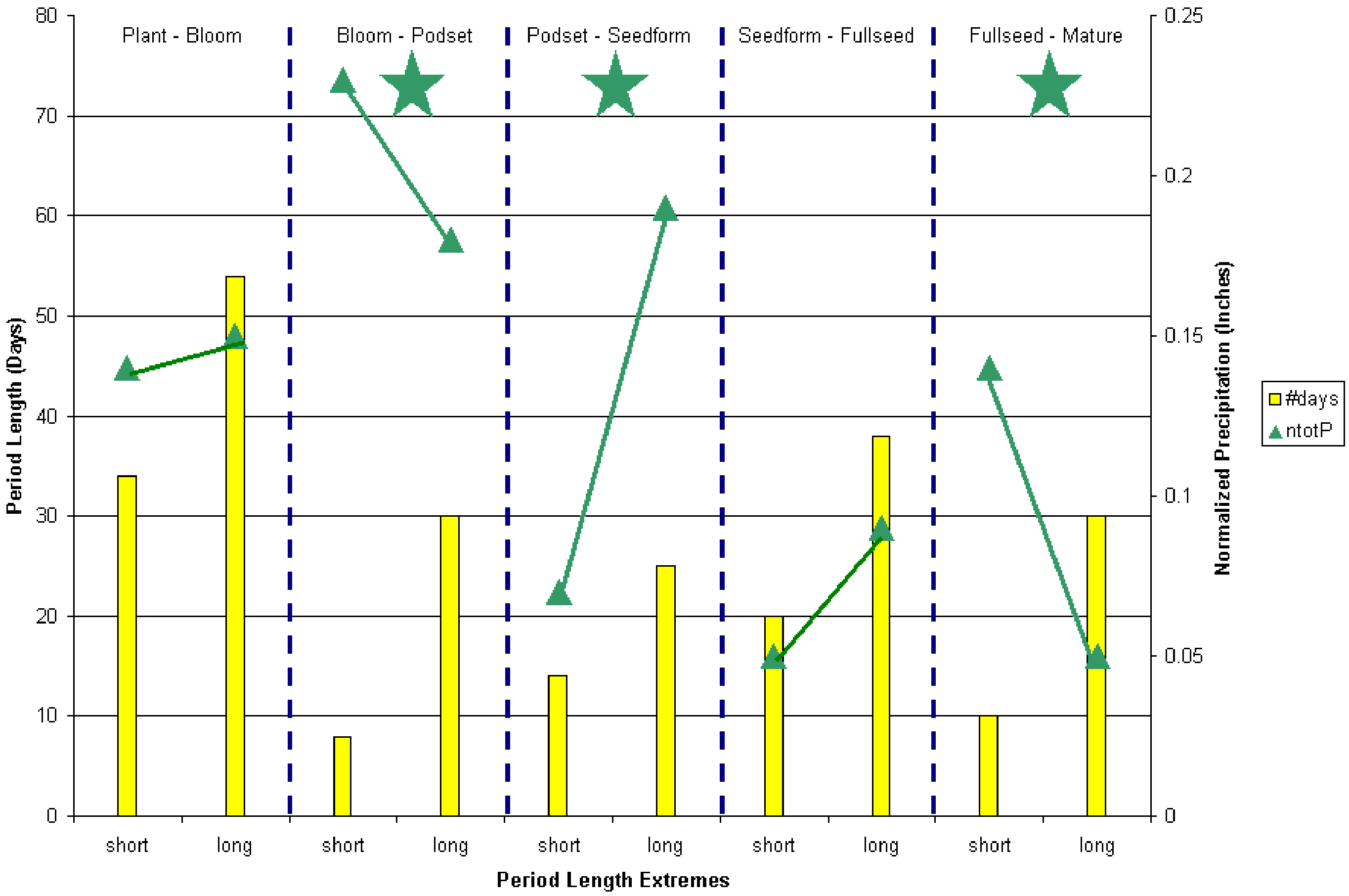


Figure 10: Mature Group 4 Summarized Results—The Effects of Moisture on Period Lengths

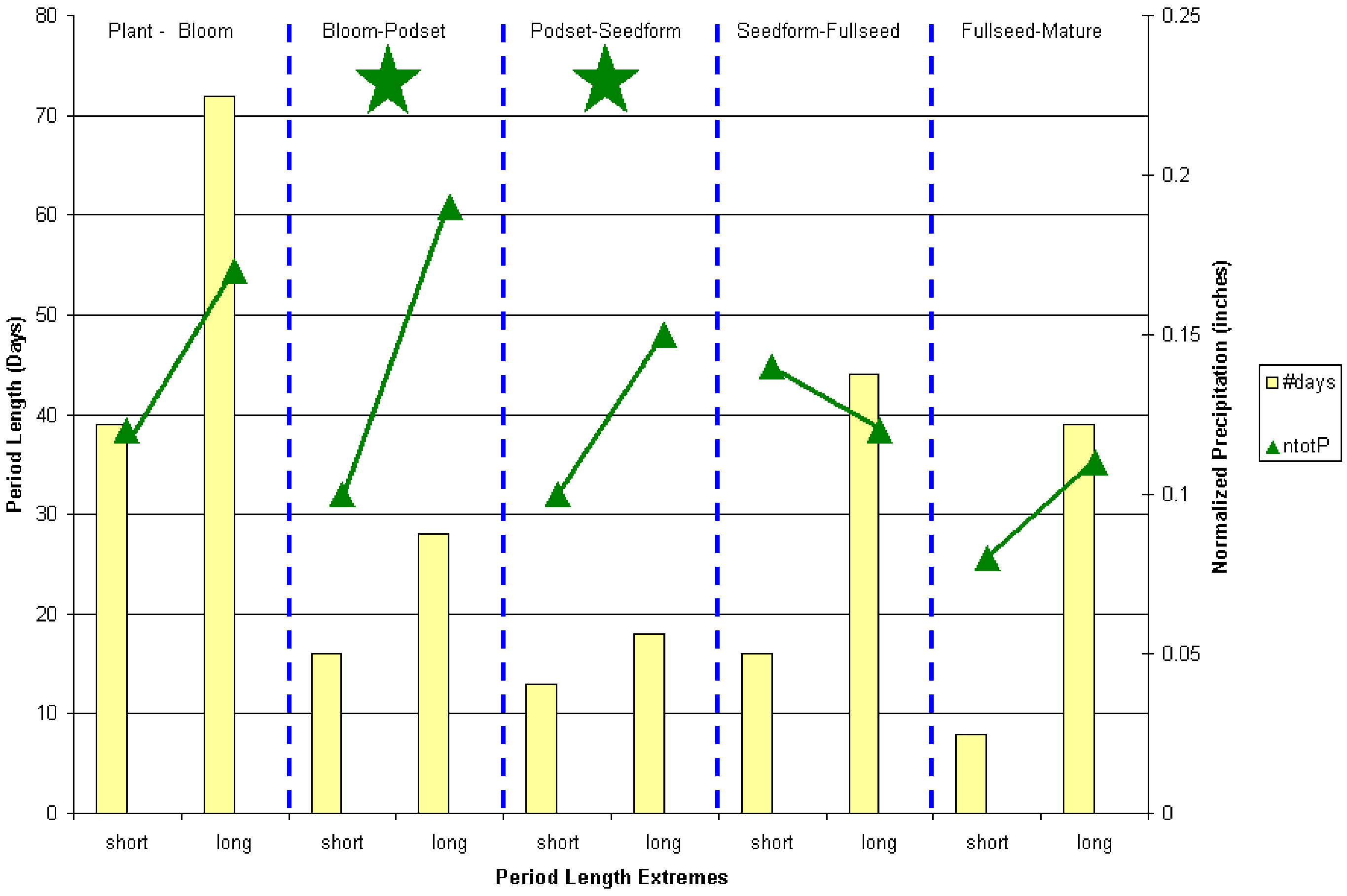


Figure 11: Mature Group 5 Summarized Resuls—The Effects of Moisture on Period Lengths

periods or between groups. It is important to note that even the extreme cases fail to demonstrate a clear relationship between water and period length. Figures 12 and 13 show the relationship between normalized +90 days, as an indicator of energy, and the same extreme cases. The only clear association revealed was in the plant to bloom period, when greater energy is linked to shorter period length. No other strong relationships appeared to exist between phenological period length and weather across both groups 4 and 5.

Analyses of Weather and Yield and Phenological Period Length and Yield

Descriptive Statistics

The analysis of the effect of weather and phenological period length on soybean yield began with descriptive statistics. Table 7 specifies the descriptive statistics that were calculated for the all of the cases of Mature Group 4. The cases were sorted by yield into the following four yield categories: less than 20.0 bushels per acre, between 20.1 and 30.0 bushels, between 30.1and 40.0 bushels, and over 40.1 bushels per acre. The categories were developed to try to see if any differences in the weather variables could be determined based on comparing the lower yielding soybeans to the higher yielding soybeans. In Table 7 several important trends became evident. First, the average planting date of the less than 20.0 bushels per acre soybeans was almost a month later than the higher yield soybeans at 40.0 bushels per acre. Second, the lower yielding soybeans had an average total growing period of 129 days, while the above 40.0 bushels per acre soybeans grew

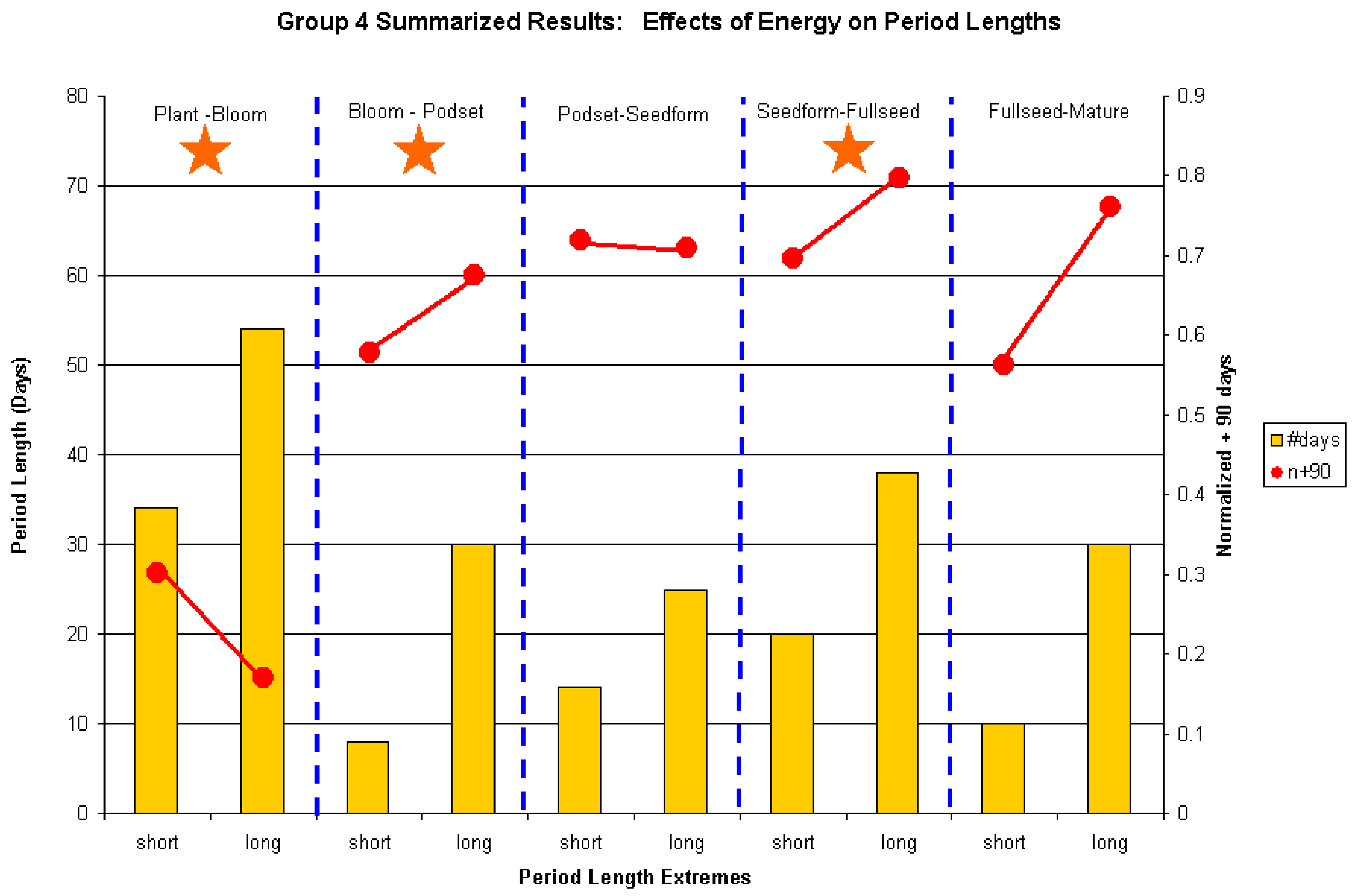


Figure 12: Mature Group 4 Summarized Results—The Effects of Energy on Period Lengths

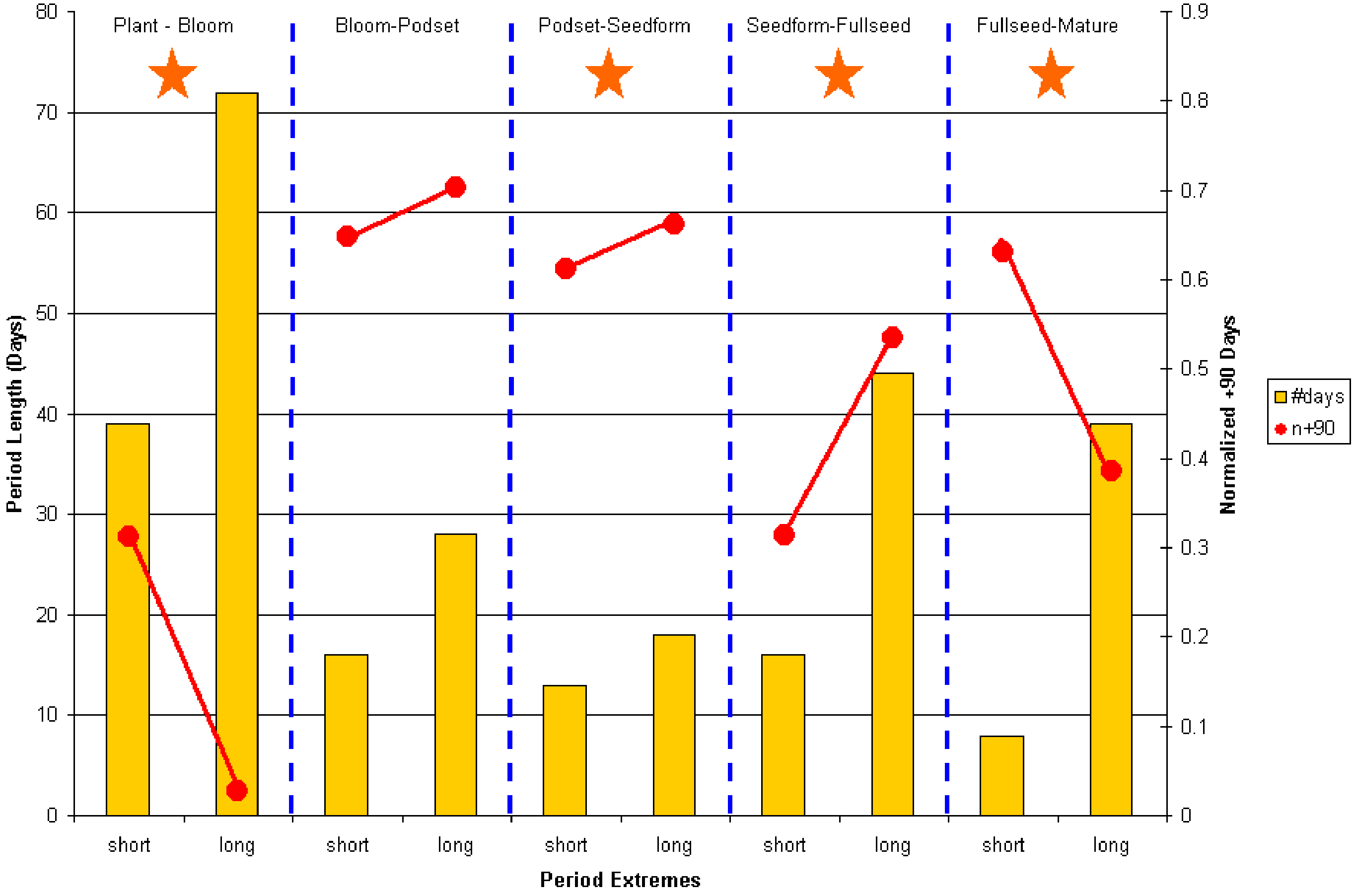
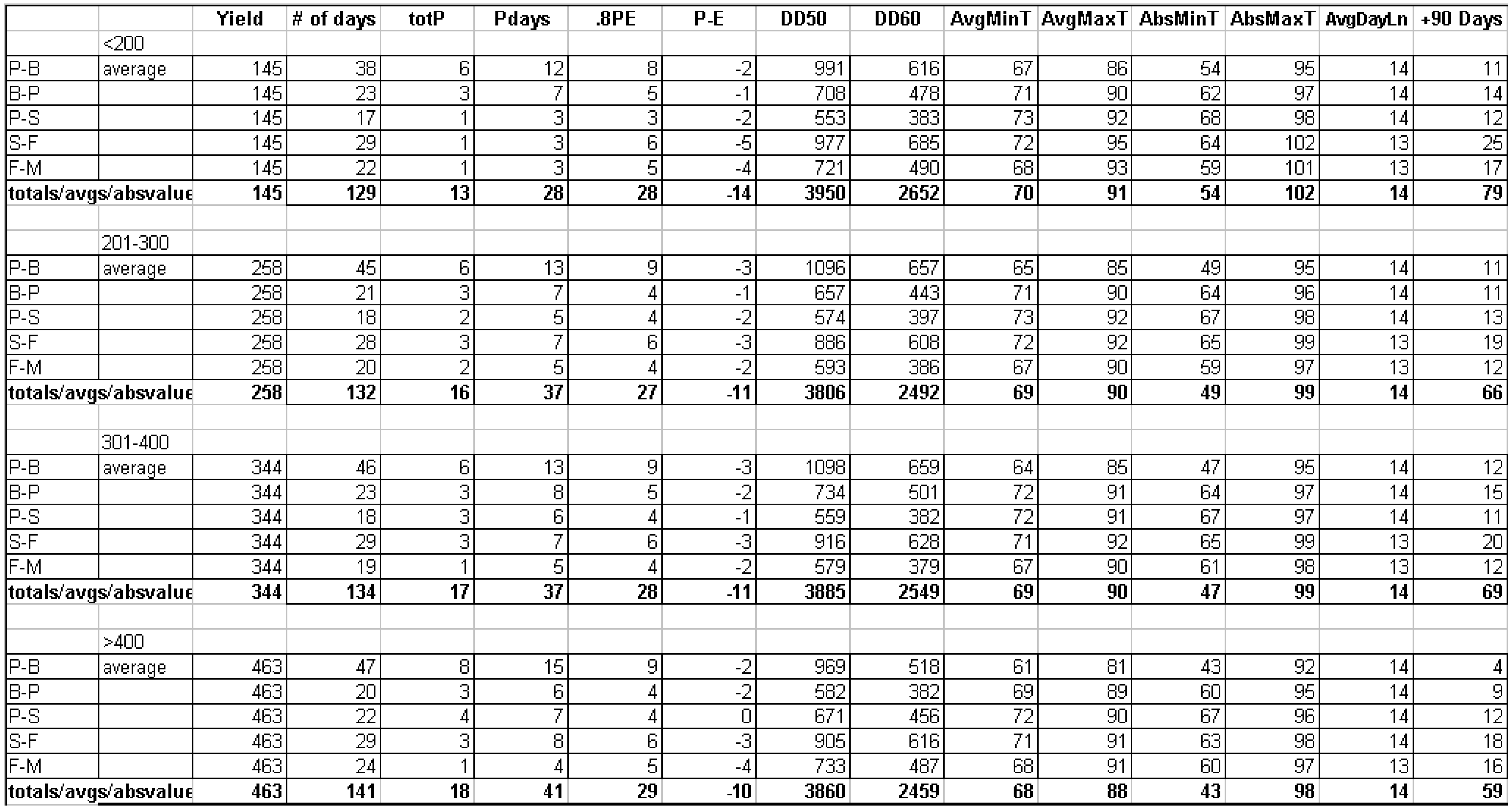


Figure 13: Mature Group 5 Summarized Results—The Effects of Energy on Period Lengths

Table 7: Mature Group 4 Descriptive Statistics for Entire Growing Period



		Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
	<200														
P-B	average	145	38	6	12	8	-2	991	616	67	86	54	95	14	11
B-P		145	23	3	7	5	-1	708	478	71	90	62	97	14	14
P-S		145	17	1	3	3	-2	553	383	73	92	68	98	14	12
S-F		145	29	1	3	6	-5	977	685	72	95	64	102	13	25
F-M		145	22	1	3	5	-4	721	490	68	93	59	101	13	17
totals/avgs/absvalue		**145**	**129**	**13**	**28**	**28**	**-14**	**3950**	**2652**	**70**	**91**	**54**	**102**	**14**	**79**
	201-300														
P-B	average	258	45	6	13	9	-3	1096	657	65	85	49	95	14	11
B-P		258	21	3	7	4	-1	657	443	71	90	64	96	14	11
P-S		258	18	2	5	4	-2	574	397	73	92	67	98	14	13
S-F		258	28	3	7	6	-3	886	608	72	92	65	99	13	19
F-M		258	20	2	5	4	-2	593	386	67	90	59	97	13	12
totals/avgs/absvalue		**258**	**132**	**16**	**37**	**27**	**-11**	**3806**	**2492**	**69**	**90**	**49**	**99**	**14**	**66**
	301-400														
P-B	average	344	46	6	13	9	-3	1098	659	64	85	47	95	14	12
B-P		344	23	3	8	5	-2	734	501	72	91	64	97	14	15
P-S		344	18	3	6	4	-1	559	382	72	91	67	97	14	11
S-F		344	29	3	7	6	-3	916	628	71	92	65	99	13	20
F-M		344	19	1	5	4	-2	579	379	67	90	61	98	13	12
totals/avgs/absvalue		**344**	**134**	**17**	**37**	**28**	**-11**	**3885**	**2549**	**69**	**90**	**47**	**99**	**14**	**69**
	>400														
P-B	average	463	47	8	15	9	-2	969	518	61	81	43	92	14	4
B-P		463	20	3	6	4	-2	582	382	69	89	60	95	14	9
P-S		463	22	4	7	4	0	671	456	72	90	67	96	14	12
S-F		463	29	3	8	6	-3	905	616	71	91	63	98	14	18
F-M		463	24	1	4	5	-4	733	487	68	91	60	97	13	16
totals/avgs/absvalue		**463**	**141**	**18**	**41**	**29**	**-10**	**3860**	**2459**	**68**	**88**	**43**	**98**	**14**	**59**

Table 7 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
126	90	85	67	51	38	21	18	11	7	4	2	1	1
134	115	96	79	62	47	33	22	14	9	6	3	2	1
122	107	93	79	66	53	41	31	24	16	11	7	4	2
300	272	244	217	191	165	140	116	92	70	52	36	24	15
229	208	187	167	149	131	113	97	81	67	54	42	33	25
911	**792**	**705**	**609**	**518**	**433**	**349**	**284**	**222**	**169**	**126**	**91**	**64**	**44**
122	82	80	62	46	34	16	16	11	6	3	1	0	0
119	99	86	71	58	45	33	24	16	10	6	3	2	1
121	106	90	76	62	48	36	26	17	11	7	4	2	1
200	175	151	129	107	87	68	51	38	27	19	12	8	4
125	108	92	78	64	51	40	29	21	15	10	7	5	3
688	**569**	**500**	**416**	**337**	**265**	**193**	**146**	**103**	**69**	**44**	**27**	**17**	**10**
137	113	91	72	55	40	27	18	12	7	3	1	0	0
152	131	113	95	78	62	47	34	23	14	8	5	3	2
112	97	82	68	54	42	31	22	14	8	5	3	1	0
205	179	154	130	108	87	67	50	37	26	17	11	7	4
122	106	91	78	64	52	41	30	22	16	11	7	5	3
728	**626**	**531**	**442**	**359**	**283**	**213**	**154**	**108**	**71**	**44**	**27**	**16**	**9**
61	46	34	23	14	8	4	2	1	1	0	0	0	0
94	79	65	52	41	31	22	14	8	4	1	0	0	0
124	105	87	70	54	39	27	17	10	5	2	1	0	0
188	163	139	117	96	76	58	43	31	21	14	9	5	3
165	145	125	106	89	72	56	42	32	23	17	12	8	5
631	**538**	**450**	**369**	**294**	**226**	**168**	**119**	**82**	**54**	**35**	**22**	**13**	**8**

for an average of 141 days. Third, the higher yielding soybeans also had more total rainfall and more precipitation days, which even when normalized remained higher in the higher yielding soybeans (although normalized data was not used in considering the effects of weather on yield, as it was thought that higher totals of rainfall, for example, even with a longer period, may very well influence higher yields). Fourth, precipitation – evaporation (P-E) was less in the higher yielding soybeans (-10 inches) than in the lower yielding soybeans (-14 inches). Finally, one of the most noticeable differences between the two groups was the number of +90 days—the higher yielding soybeans had only 59 +90 days (even though they had on average a longer growing season and therefore more time to accrue +90 days), while the lower yielding soybeans had 79 total +90 days.

Table 8 for Mature Group 5 displays the same descriptive statistics with similar results. The lower yielding cases (less than 20.0 bushels per acre) on average were planted a month after the higher yielding soybeans, and had a shorter average growing season at 133 days as opposed to an average of 141 days for the higher yielding soybeans (greater than 40.0 bushels per acre). Total precipitation and precipitation days were greater in the higher yielding soybeans at 18 inches as compared to 12 inches for the less productive soybeans (even after normalization). Precipitation – evaporation (P-E) was less in the higher yielding soybeans at –10 inches whereas the lower yielding soybeans had –16 inches of P-E. As with the Mature Group 4 beans, the number of +90 days were noticeably less for the higher yielding soybeans at 57 days as opposed to 77 days for the lower yielding

Table 8: Mature Group 5 Descriptive Statistics for Entire Growing Period

		Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
	<200														
P-B	average	162	52	7	16	12	-5	1495	973	69	88	56	96	14	20
B-P		162	20	2	6	4	-2	647	451	73	92	67	99	14	15
P-S		162	16	1	2	3	-2	543	383	73	94	68	99	14	13
S-F		162	28	1	4	6	-5	874	598	69	94	59	102	13	22
F-M		162	18	1	3	4	-2	447	260	60	87	48	96	12	7
totals/averages/absvalues			**133**	**12**	**32**	**29**	**-16**	**4006**	**2664**	**69**	**91**	**56**	**102**	**13**	**77**
	201-300														
P-B	average	240	55	8	17	12	-4	1435	890	67	86	52	96	14	16
B-P		240	24	4	8	5	-1	763	525	73	91	67	97	14	17
P-S		240	16	2	4	3	-2	520	360	73	92	68	98	14	12
S-F		240	29	1	5	6	-4	920	630	71	93	62	99	13	22
F-M		240	16	2	4	3	-1	452	272	63	87	53	96	12	7
totals/averages/absvalues			**140**	**16**	**38**	**29**	**-13**	**4090**	**2678**	**69**	**90**	**52**	**99**	**13**	**74**
	301-400														
P-B	average	354	55	7	16	11	-4	1378	842	66	86	48	96	14	16
B-P		354	24	4	8	5	-1	744	507	72	91	65	96	14	14
P-S		354	15	3	5	3	0	473	321	71	90	66	96	14	9
S-F		354	31	2	8	6	-4	922	615	69	90	61	97	13	18
F-M		354	18	2	5	3	-2	499	305	64	88	56	95	12	7
totals/averages/absvalues			**143**	**18**	**42**	**29**	**-11**	**4017**	**2590**	**68**	**89**	**48**	**97**	**13**	**63**
	>400														
P-B	average	475	54	7	15	11	-4	1417	886	67	86	48	96	14	16
B-P		475	22	2	6	5	-3	702	483	72	91	65	97	14	15
P-S		475	16	3	6	3	0	481	324	72	90	67	95	14	8
S-F		475	30	3	9	5	-2	877	575	69	89	60	96	13	14
F-M		475	20	3	5	3	-1	506	298	63	86	54	93	12	5
totals/averages/absvalues			**141**	**18**	**42**	**28**	**-10**	**3983**	**2566**	**68**	**89**	**48**	**97**	**13**	**57**

Table 8 (continued)

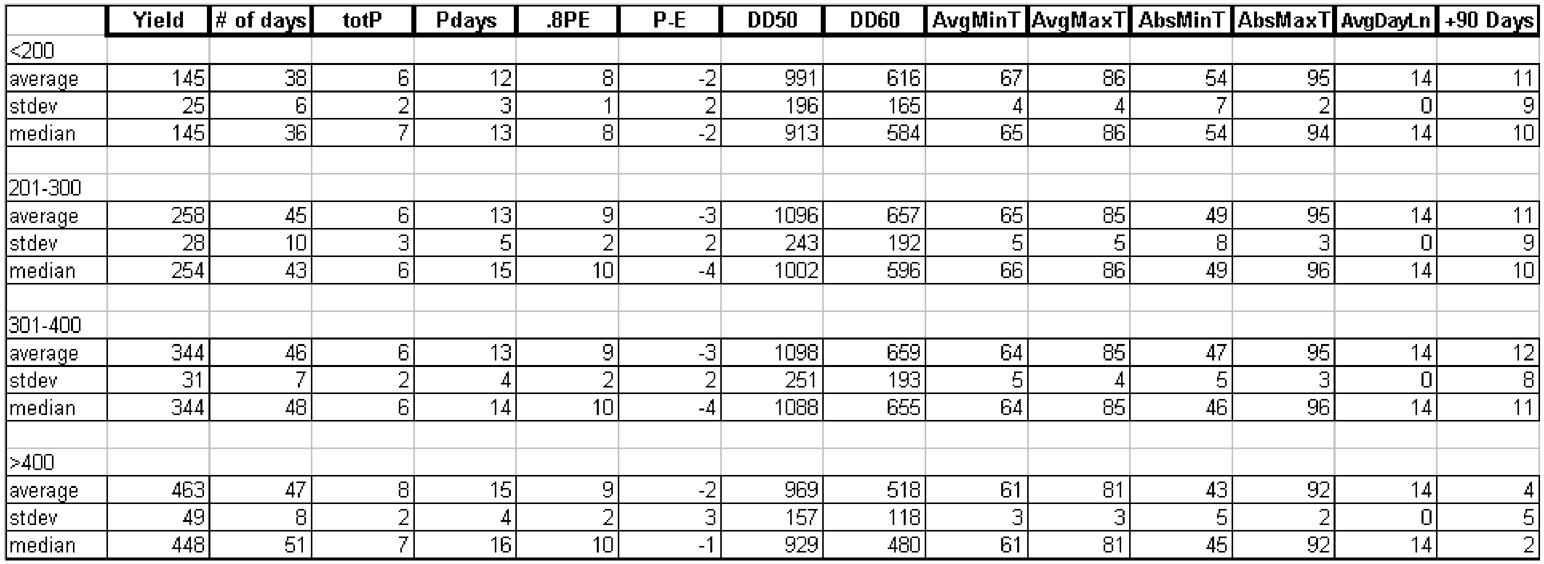
HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
219	181	146	116	89	64	44	30	18	11	6	3	1	0
150	132	114	97	82	66	52	39	30	23	17	12	9	6
154	138	123	108	94	80	66	54	43	32	24	17	11	6
258	231	206	181	157	135	112	91	72	54	40	27	17	11
84	71	59	48	39	32	25	18	12	8	5	3	1	1
863	**754**	**648**	**550**	**460**	**377**	**300**	**232**	**176**	**129**	**93**	**62**	**39**	**23**
191	157	127	99	75	54	37	25	16	9	4	2	0	0
163	142	121	101	81	63	47	33	22	14	9	5	4	2
119	105	91	77	64	51	39	29	22	16	11	7	5	2
236	210	184	160	136	113	92	72	55	40	29	20	13	7
74	63	52	42	33	26	19	13	8	5	3	2	1	0
783	**676**	**575**	**478**	**389**	**307**	**233**	**172**	**124**	**85**	**56**	**36**	**22**	**12**
174	143	116	90	68	49	33	21	13	7	2	1	0	0
146	125	105	87	69	53	40	27	17	9	5	2	1	1
88	75	62	51	40	31	22	15	10	6	4	2	1	0
183	157	133	110	89	69	51	36	26	18	12	8	5	2
76	63	51	40	31	23	16	10	6	4	2	1	1	0
666	**563**	**466**	**379**	**298**	**226**	**162**	**110**	**72**	**44**	**25**	**14**	**8**	**4**
192	159	128	100	76	56	40	27	17	10	4	1	0	0
149	129	109	91	73	58	43	30	20	13	8	5	3	2
82	68	56	44	34	25	17	11	6	4	2	1	1	0
147	123	101	82	64	47	33	22	14	9	6	3	2	1
60	49	38	30	22	16	11	8	5	4	2	2	1	0
630	**528**	**433**	**347**	**268**	**201**	**144**	**98**	**63**	**39**	**23**	**13**	**7**	**4**

cases, even though the higher yielding cases had, on average, more days (or more opportunitues) to accrue +90 days.

In order to try to isolate in which period a given weather variable or phenological period length might be important to yield, these same type of descriptive statistics were found for each of the phenological periods for both Maturity Groups. Tables 9 – 18 display the descriptive statistics for each of the phenological periods for both Maturity Groups 4 and 5. For example, Table 9 displays the descriptive results for the plant to bloom period of Mature Group 4. The lower yielding cases had a much shorter plant to bloom growing period at an average of 38 days as compared to an average of 47 days for the higher yielding beans. In addition, the higher yielding soybeans had more precipitation and precipitation days during the plant to bloom period than the lower yielding soybeans. The number of days over 90 degrees in the plant to bloom period also decreased markedly for the higher yielding soybeans—only 4 days as opposed to 11 days for the lower yield soybeans. However, for the Mature Group 5 plant to bloom period, these same trends were not present. Table 10 shows that the number of days in the plant to bloom period remained around the same value in all of the yield cases, as did the amount of precipitation and the number of precipitation days. +90 Days decreased slightly for the higher yield soybeans—16 days as compared to 20 days for the lower yielding soybeans.

Tables 11 and 12 display the descriptive statistics for the bloom to podset period for Mature Groups 4 and 5, respectively. In Table 11 for Mature Group 4 no

Table 9: Mature Group 4 Descriptive Statistics for Plant - Bloom Period



	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	145	38	6	12	8	-2	991	616	67	86	54	95	14	11
stdev	25	6	2	3	1	2	196	165	4	4	7	2	0	9
median	145	36	7	13	8	-2	913	584	65	86	54	94	14	10
201-300														
average	258	45	6	13	9	-3	1096	657	65	85	49	95	14	11
stdev	28	10	3	5	2	2	243	192	5	5	8	3	0	9
median	254	43	6	15	10	-4	1002	596	66	86	49	96	14	10
301-400														
average	344	46	6	13	9	-3	1098	659	64	85	47	95	14	12
stdev	31	7	2	4	2	2	251	193	5	4	5	3	0	8
median	344	48	6	14	10	-4	1088	655	64	85	46	96	14	11
>400														
average	463	47	8	15	9	-2	969	518	61	81	43	92	14	4
stdev	49	8	2	4	2	3	157	118	3	3	5	2	0	5
median	448	51	7	16	10	-1	929	480	61	81	45	92	14	2

Table 9 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
126	90	85	67	51	38	21	18	11	7	4	2	1	1
88	64	72	64	56	47	29	30	22	15	9	5	3	2
114	66	73	55	38	24	12	6	2	0	0	0	0	0
122	82	80	62	46	34	16	16	11	6	3	1	0	0
84	50	67	58	50	42	16	26	19	12	7	2	0	0
123	90	81	62	43	29	18	10	6	3	1	0	0	0
137	113	91	72	55	40	27	18	12	7	3	1	0	0
74	66	59	51	44	37	31	23	17	11	6	2	0	0
135	112	89	66	47	31	18	10	6	3	1	0	0	0
61	46	34	23	14	8	4	2	1	1	0	0	0	0
40	34	28	22	17	12	7	5	3	1	1	0	0	0
48	34	23	15	8	4	2	0	0	0	0	0	0	0

	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	162	52	7	16	12	-5	1495	973	69	88	56	96	14	20
stdev	29	4	1	3	1	1	97	81	2	2	5	2	0	7
median	166	51	7	15	12	-5	1495	960	70	88	56	96	14	20
201-300														
average	240	55	8	17	12	-4	1435	890	67	86	52	96	14	16
stdev	28	8	3	4	1	2	138	119	3	3	7	1	0	8
median	237	53	7	16	12	-5	1459	885	67	87	54	96	14	15
301-400														
average	354	55	7	16	11	-4	1378	842	66	86	48	96	14	16
median	28	8	3	5	1	3	169	145	4	4	7	2	0	8
stdev	352	53	6	18	11	-5	1438	846	66	86	47	97	14	14
>400														
average	475	54	7	15	11	-4	1417	886	67	86	48	96	14	16
stdev	59	6	2	4	1	2	152	138	3	3	7	2	0	8
median	460	52	7	17	11	-5	1403	886	67	87	46	97	14	16

Table 10 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
219	181	146	116	89	64	44	30	18	11	6	3	1	0
73	71	67	62	57	51	45	36	27	18	10	4	2	1
190	154	120	87	60	38	23	13	6	3	1	0	0	0
191	157	127	99	75	54	37	25	16	9	4	2	0	0
72	66	60	54	48	42	35	28	21	14	8	4	1	1
190	154	120	87	60	38	23	13	7	3	1	0	0	0
174	143	116	90	68	49	33	21	13	7	2	1	0	0
71	64	55	48	40	33	26	19	13	8	4	1	0	0
164	134	108	83	62	43	26	15	9	4	2	1	0	0
192	159	128	100	76	56	40	27	17	10	4	1	0	0
77	71	63	56	49	41	34	26	19	12	7	2	0	0
197	163	130	100	73	51	35	23	13	6	2	1	0	0

Table 11: Mature Group 4 Descriptive Statistics for Bloom – Podset Period

	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	145	23	3	7	5	-1	708	478	71	90	62	97	14	14
stdev	25	4	2	3	1	1	113	79	2	2	6	2	0	3
median	145	24	4	7	5	-1	731	492	71	90	62	97	14	13
201-300														
average	259	21	3	7	4	-1	657	443	71	90	64	96	14	11
stdev	29	5	2	3	1	2	190	142	3	3	5	3	0	7
median	255	22	3	6	5	-1	682	465	72	90	65	97	14	13
301-400														
average	346	23	3	8	5	-2	734	501	72	91	64	97	14	15
stdev	30	7	3	4	2	2	251	184	3	2	6	2	0	7
median	345	22	2	7	5	-2	721	486	72	91	65	97	14	14
>400														
average	463	20	3	6	4	-2	582	382	69	89	60	95	14	9
stdev	49	3	1	1	1	1	116	85	2	2	5	3	0	6
median	448	21	3	6	5	-2	588	383	69	89	59	96	14	8

Table 11 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
134	115	96	79	62	47	33	22	14	9	6	3	2	1
38	36	34	32	29	27	25	22	19	15	12	9	7	4
126	110	97	81	62	44	31	19	9	6	3	1	0	0
119	99	86	71	58	45	33	24	16	10	6	3	2	1
67	62	56	50	44	38	32	26	22	17	14	10	7	5
96	80	64	50	39	29	21	15	9	4	2	1	0	0
152	131	113	95	78	62	47	34	23	14	8	5	3	2
78	71	66	59	53	47	40	35	29	23	18	13	9	6
135	116	98	81	67	53	39	25	14	7	2	1	0	0
94	79	65	52	41	31	22	14	8	4	1	0	0	0
46	41	36	31	26	21	15	10	5	2	1	1	0	0
82	67	54	42	33	24	16	11	7	3	1	0	0	0

Table 12: Mature Group 5 Descriptive Statistics for Bloom – Podset Period

	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	162	20	2	6	4	-2	647	451	73	92	67	99	14	15
stdev	29	4	1	3	1	1	150	110	2	2	3	2	0	4
median	166	19	1	6	4	-2	605	422	73	92	64	97	14	14
201-300														
average	240	24	4	8	5	-1	763	525	73	91	67	97	14	17
stdev	28	5	3	3	1	3	184	134	2	2	3	2	0	6
median	237	24	3	8	5	-2	774	524	73	91	66	96	14	17
301-400														
average	354	24	4	8	5	-1	744	507	72	91	65	96	14	14
median	28	4	3	3	1	3	145	106	2	2	4	2	0	6
stdev	352	25	2	8	5	-2	774	534	72	91	65	97	14	14
>400														
average	475	22	2	6	5	-3	702	483	72	91	65	97	14	15
stdev	59	5	2	3	1	2	169	124	2	2	5	2	0	5
median	460	22	2	6	5	-4	745	514	73	92	65	97	14	17

Table 12 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
150	132	114	97	82	66	52	39	30	23	17	12	9	6
61	59	56	54	50	47	44	41	36	29	24	19	14	10
125	105	87	73	54	39	25	12	7	4	2	1	0	0
163	142	121	101	81	63	47	33	22	14	9	5	4	2
62	57	53	49	44	40	35	30	25	19	15	11	8	5
157	134	114	96	78	60	39	24	13	6	1	0	0	0
146	125	105	87	69	53	40	27	17	9	5	2	1	1
50	47	43	39	35	31	25	20	15	11	9	6	5	3
142	121	100	81	65	50	36	25	16	8	4	2	0	0
149	129	109	91	73	58	43	30	20	13	8	5	3	2
56	53	49	45	41	37	33	28	24	19	15	11	9	6
160	136	113	91	71	55	41	28	18	10	4	2	0	0

distinct difference between the high yielding soybeans and the low yielding soybeans is apparent. The number of days in the period remains the same, total precipitation and the number of precipitation days remains pretty constant across the yield categories, and the number of days above 90 degrees varies only by 5 days between the highest and lowest yield categories. Table 12 for Mature Group 5 also displays little variation between the yield categories.

The podset to seedform period for Maturity Group 4 showed some variation between the yield categories. Table 13 shows that the amount of precipitation increases for the higher yield category (1" as opposed to 4") as well as the number of precipitation days (3 days as opposed to 7 days). Mature Group 5 podset to seedform in Table 14 also demonstrated that the higher yielding soybeans had higher amounts of precipitation (3" as opposed to 1") as well as more precipitation days (2 days as opposed to 6 days). The number of +90 days varied by 5 days between the highest and lowest yield categories.

Tables 15 and 16 display the statistics for the seedform to fullseed for Maturity Groups 4 and 5. For Mature Group 4 in Table 15, higher precipitation (1" compared to 3") and higher precipitation days (as well as fewer +90 days) were associated with higher yield. Mature Group 5 in Table 16 showed the same trend—more precipitation and precipitation days, coupled with fewer +90 days were again associated with the higher yielding soybeans.

The final phenological period, fullseed to mature, is displayed in Tables 17 and 18 for Mature Groups 4 and 5. Table 17 shows that there is little variability in

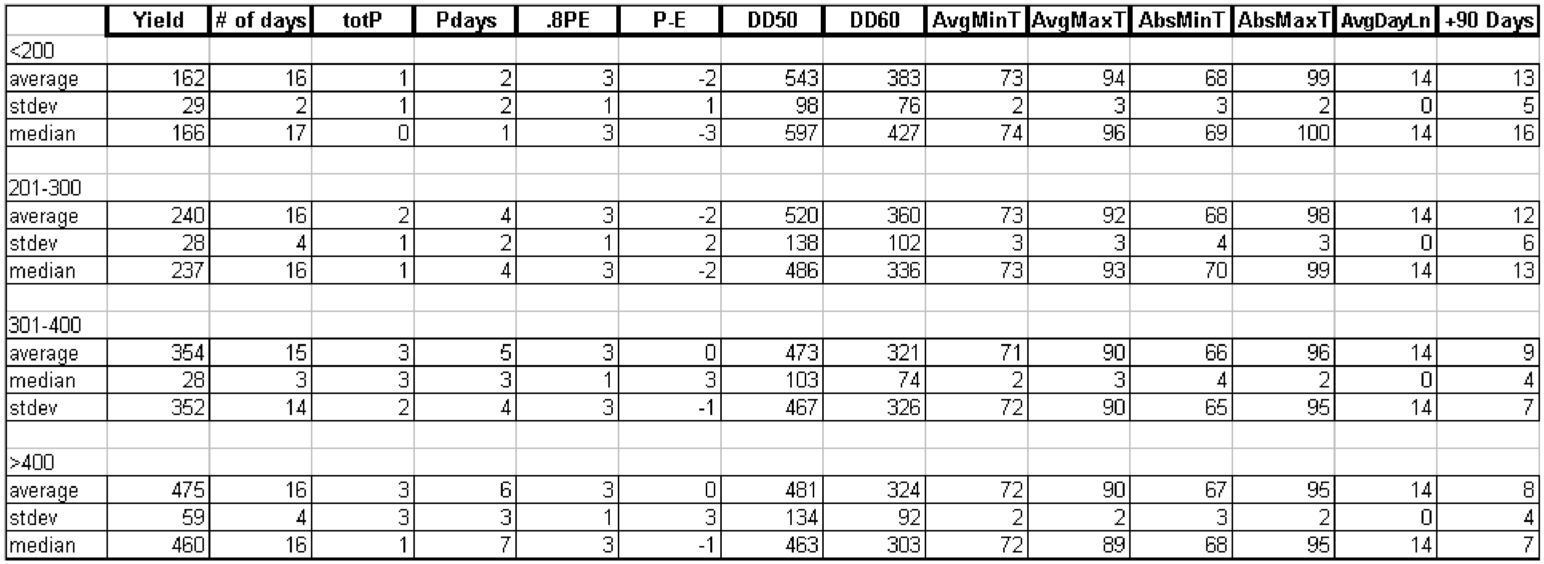
Table 13: Mature Group 4 Descriptive Statistics for Podset – Seedform Period

	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	145	17	1	3	3	-2	553	383	73	92	68	98	14	12
stdev	25	4	1	3	1	1	124	87	1	2	2	2	0	4
median	145	16	2	2	3	-2	519	364	73	92	68	98	14	13
201-300														
average	258	18	2	5	4	-2	574	397	73	92	67	98	14	13
stdev	28	4	2	3	1	2	140	103	2	3	4	2	0	5
median	254	17	1	4	3	-2	551	381	73	92	69	97	14	13
301-400														
average	344	18	3	6	4	-1	559	382	72	91	67	97	14	11
stdev	31	4	3	4	1	3	124	86	2	2	4	2	0	5
median	344	18	2	5	3	-1	529	374	73	91	67	97	14	11
>400														
average	463	22	4	7	4	0	671	456	72	90	67	96	14	12
stdev	49	5	3	4	1	3	165	115	2	2	2	2	0	5
median	448	21	2	7	5	-1	638	438	72	90	67	96	14	12

Table 13 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
122	107	93	79	66	53	41	31	24	16	11	7	4	2
41	38	36	34	31	29	26	23	19	16	13	9	7	4
124	105	87	75	60	49	40	27	17	12	8	4	1	0
121	106	90	76	62	48	36	26	17	11	7	4	2	1
44	41	38	35	31	28	25	21	17	14	11	8	6	4
125	109	94	78	63	49	34	23	14	8	4	1	0	0
112	97	82	68	54	42	31	22	14	8	5	3	1	0
41	38	35	31	28	24	19	15	11	8	6	4	2	1
109	96	83	70	57	46	36	25	15	7	3	2	0	0
124	105	87	70	54	39	27	17	10	5	2	1	0	0
40	36	33	30	27	23	19	14	9	5	2	1	0	0
125	107	90	72	55	40	27	16	9	4	2	1	0	0

Table 14: Mature Group 5 Descriptive Statistics for Podset – Seedform Period



	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	162	16	1	2	3	-2	543	383	73	94	68	99	14	13
stdev	29	2	1	2	1	1	98	76	2	3	3	2	0	5
median	166	17	0	1	3	-3	597	427	74	96	69	100	14	16
201-300														
average	240	16	2	4	3	-2	520	360	73	92	68	98	14	12
stdev	28	4	1	2	1	2	138	102	3	3	4	3	0	6
median	237	16	1	4	3	-2	486	336	73	93	70	99	14	13
301-400														
average	354	15	3	5	3	0	473	321	71	90	66	96	14	9
median	28	3	3	3	1	3	103	74	2	3	4	2	0	4
stdev	352	14	2	4	3	-1	467	326	72	90	65	95	14	7
>400														
average	475	16	3	6	3	0	481	324	72	90	67	95	14	8
stdev	59	4	3	3	1	3	134	92	2	2	3	2	0	4
median	460	16	1	7	3	-1	463	303	72	89	68	95	14	7

Table 14 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
154	138	123	108	94	80	66	54	43	32	24	17	11	6
57	54	52	49	45	41	37	32	27	22	17	12	8	5
173	154	136	122	109	96	82	66	54	42	32	23	15	8
119	105	91	77	64	51	39	29	22	16	11	7	5	2
49	45	42	38	34	30	26	22	19	15	12	8	6	4
119	104	89	75	61	50	36	27	20	14	9	6	4	2
88	75	62	51	40	31	22	15	10	6	4	2	1	0
36	34	32	29	26	23	20	16	13	10	8	5	3	1
78	64	51	41	31	22	14	7	4	2	0	0	0	0
82	68	56	44	34	25	17	11	6	4	2	1	1	0
35	31	28	25	22	19	15	12	9	7	5	4	3	1
78	63	48	35	25	19	12	6	2	1	0	0	0	0

Table 15: Mature Group 4 Descriptive Statistics for Seedform – Fullseed Period

	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	145	29	1	3	6	-5	977	685	72	95	64	102	13	25
stdev	25	5	1	1	1	1	161	113	1	1	3	1	0	4
median	145	30	1	3	6	-5	990	690	72	95	65	102	14	25
201-300														
average	258	28	3	7	6	-3	886	608	72	92	65	99	13	19
stdev	28	6	1	4	1	2	198	144	2	2	5	2	0	6
median	254	29	3	7	6	-3	912	631	72	92	63	99	13	18
301-400														
average	344	29	3	7	6	-3	916	628	71	92	65	99	13	20
stdev	31	6	2	4	1	2	232	174	3	2	4	3	0	8
median	344	30	2	7	6	-3	963	665	72	91	64	99	14	19
>400														
average	463	29	3	8	6	-3	905	616	71	91	63	98	14	18
stdev	49	4	2	4	1	2	173	133	2	2	4	3	0	9
median	448	29	4	8	6	-2	926	636	72	92	63	99	14	20

Table 15 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
300	272	244	217	191	165	140	116	92	70	52	36	24	15
55	51	47	43	40	36	33	30	27	23	20	16	13	10
306	276	246	217	189	163	137	112	89	68	49	33	21	14
200	175	151	129	107	87	68	51	38	27	19	12	8	4
67	63	59	54	50	45	40	35	29	23	17	12	8	5
197	176	157	137	113	92	73	54	37	25	15	9	4	2
205	179	154	130	108	87	67	50	37	26	17	11	7	4
80	75	70	64	58	52	45	38	31	23	17	12	8	4
199	168	143	120	98	75	51	33	21	13	7	5	3	1
188	163	139	117	96	76	58	43	31	21	14	9	5	3
79	74	68	62	56	50	43	36	28	20	14	9	6	4
209	186	163	142	116	86	57	38	25	16	9	6	4	2

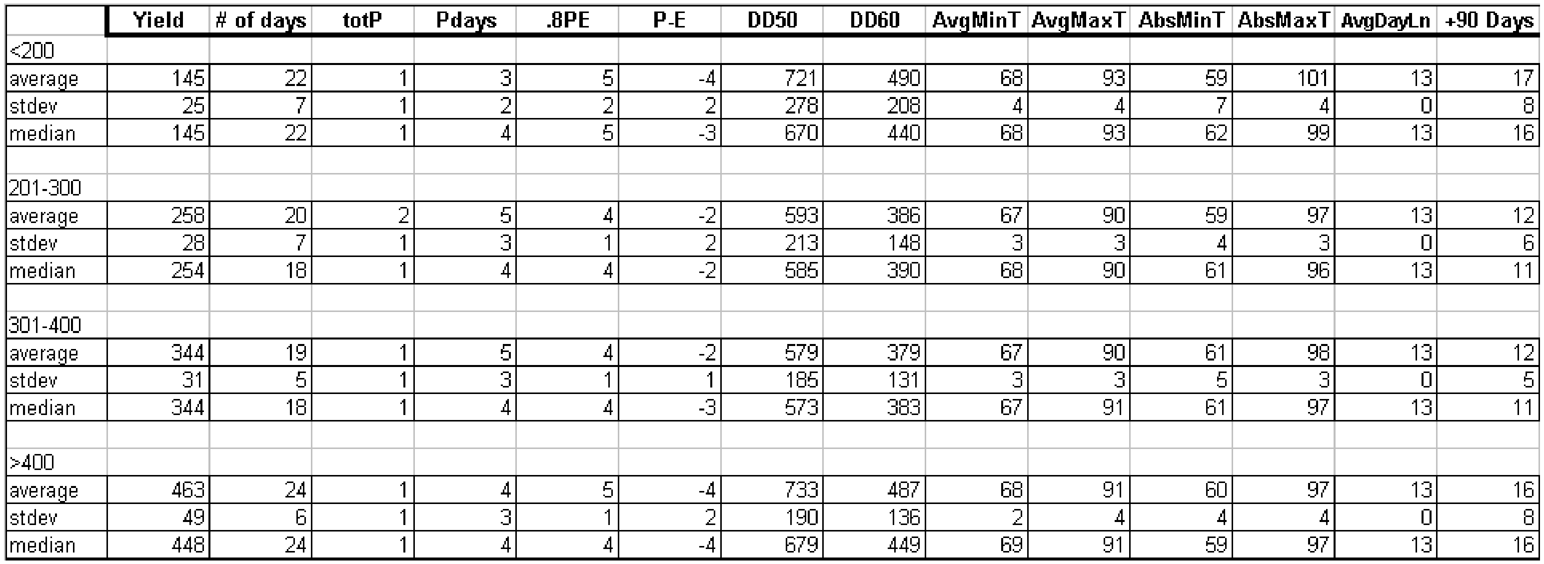
Table 16: Mature Group 5 Descriptive Statistics for Seedform – Fullseed Period

	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	162	28	1	4	6	-5	874	598	69	94	59	102	13	22
stdev	29	7	0	1	2	2	233	163	1	2	4	3	0	8
median	166	28	1	4	7	-5	918	638	69	94	61	104	13	25
201-300														
average	240	29	1	5	6	-4	920	630	71	93	62	99	13	22
stdev	28	6	1	2	1	2	200	150	3	3	5	3	0	8
median	237	29	1	5	6	-4	907	601	71	94	61	101	13	22
301-400														
average	354	31	2	8	6	-4	922	615	69	90	61	97	13	18
median	28	6	2	3	2	3	228	174	3	3	4	3	0	10
stdev	352	31	2	7	6	-4	904	599	69	90	61	97	13	17
>400														
average	475	30	3	9	5	-2	877	575	69	89	60	96	13	14
stdev	59	8	2	5	2	2	250	172	2	2	4	2	0	8
median	460	31	4	8	6	-1	875	583	68	89	61	96	13	16

Table 16 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
258	231	206	181	157	135	112	91	72	54	40	27	17	11
102	95	87	80	73	65	57	49	41	32	24	17	11	7
287	257	226	197	171	145	120	98	77	58	43	29	18	11
236	210	184	160	136	113	92	72	55	40	29	20	13	7
94	88	81	74	67	60	52	45	37	29	22	16	11	6
250	224	202	180	158	136	114	92	70	49	35	21	14	8
183	157	133	110	89	69	51	36	26	18	12	8	5	2
97	90	82	74	65	56	47	40	32	24	18	13	9	5
153	132	111	92	71	52	35	22	12	6	3	1	0	0
147	123	101	82	64	47	33	22	14	9	6	3	2	1
70	63	57	51	45	38	31	25	20	15	11	8	5	3
160	130	106	85	65	47	30	15	6	3	1	0	0	0

Table 17: Mature Group 4 Descriptive Statistics for Fullseed – Mature Period

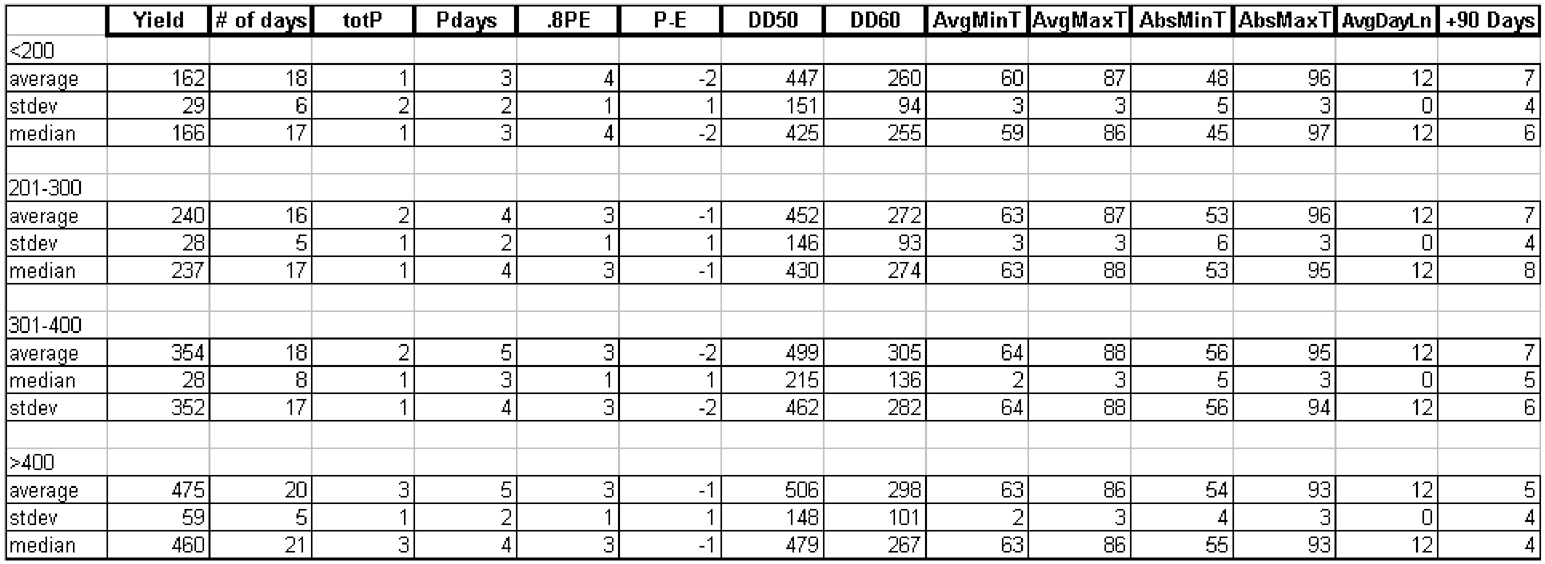


	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	145	22	1	3	5	-4	721	490	68	93	59	101	13	17
stdev	25	7	1	2	2	2	278	208	4	4	7	4	0	8
median	145	22	1	4	5	-3	670	440	68	93	62	99	13	16
201-300														
average	258	20	2	5	4	-2	593	386	67	90	59	97	13	12
stdev	28	7	1	3	1	2	213	148	3	3	4	3	0	6
median	254	18	1	4	4	-2	585	390	68	90	61	96	13	11
301-400														
average	344	19	1	5	4	-2	579	379	67	90	61	98	13	12
stdev	31	5	1	3	1	1	185	131	3	3	5	3	0	5
median	344	18	1	4	4	-3	573	383	67	91	61	97	13	11
>400														
average	463	24	1	4	5	-4	733	487	68	91	60	97	13	16
stdev	49	6	1	3	1	2	190	136	2	4	4	4	0	8
median	448	24	1	4	4	-4	679	449	69	91	59	97	13	16

Table 17 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
229	208	187	167	149	131	113	97	81	67	54	42	33	25
130	123	116	109	101	94	86	79	71	63	54	46	38	30
185	170	155	135	114	94	75	57	40	26	17	10	3	1
125	108	92	78	64	51	40	29	21	15	10	7	5	3
74	70	65	60	55	50	45	40	35	30	25	21	17	13
107	92	81	69	56	42	31	21	12	5	2	0	0	0
122	106	91	78	64	52	41	30	22	16	11	7	5	3
58	54	51	47	43	39	35	31	27	22	18	14	11	8
105	93	77	63	50	39	27	17	11	5	3	1	0	0
165	145	125	106	89	72	56	42	32	23	17	12	8	5
85	80	74	68	62	56	50	43	36	29	23	17	12	8
162	140	118	98	78	58	39	23	13	5	2	1	0	0

Table 18: Mature Group 5 Descriptive Statistics for Fullseed – Mature Period



	Yield	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT	AbsMaxT	AvgDayLn	+90 Days
<200														
average	162	18	1	3	4	-2	447	260	60	87	48	96	12	7
stdev	29	6	2	2	1	1	151	94	3	3	5	3	0	4
median	166	17	1	3	4	-2	425	255	59	86	45	97	12	6
201-300														
average	240	16	2	4	3	-1	452	272	63	87	53	96	12	7
stdev	28	5	1	2	1	1	146	93	3	3	6	3	0	4
median	237	17	1	4	3	-1	430	274	63	88	53	95	12	8
301-400														
average	354	18	2	5	3	-2	499	305	64	88	56	95	12	7
median	28	8	1	3	1	1	215	136	2	3	5	3	0	5
stdev	352	17	1	4	3	-2	462	282	64	88	56	94	12	6
>400														
average	475	20	3	5	3	-1	506	298	63	86	54	93	12	5
stdev	59	5	1	2	1	1	148	101	2	3	4	3	0	4
median	460	21	3	4	3	-1	479	267	63	86	55	93	12	4

Table 18 (continued)

HT85	HT86	HT87	HT88	HT89	HT90	HT91	HT92	HT93	HT94	HT95	HT96	HT97	HT98
84	71	59	48	39	32	25	18	12	8	5	3	1	1
42	38	35	31	28	24	20	16	12	9	6	4	2	1
80	67	54	45	37	30	24	19	14	10	6	4	2	1
74	63	52	42	33	26	19	13	8	5	3	2	1	0
36	32	29	26	22	19	15	12	9	7	5	3	2	1
70	59	48	39	31	23	15	8	4	1	0	0	0	0
76	63	51	40	31	23	16	10	6	4	2	1	1	0
43	39	34	30	26	21	17	14	11	8	6	4	2	1
61	50	39	30	22	15	9	4	2	0	0	0	0	0
60	49	38	30	22	16	11	8	5	4	2	2	1	0
41	37	34	30	27	23	19	15	12	8	6	4	2	1
59	45	33	21	13	8	4	2	0	0	0	0	0	0

the variables between the high yielding soybeans and the low yielding soybeans for Maturity Group 4. However, for the Group 5 beans, the higher yielding soybeans were associated with more precipitation and more precipitation days.

In addition to ranking all the cases by yield and finding the average weather associated with the yield levels, the highest and lowest yield cases were found for each of the maturity groups. The highest and lowest cases for each maturity group were made into a chart that contained a "totals" line that contained the averages, absolute values, and summed totals of all the weather variables in order to see if there were any discernable differences between the two cases. Table 19 displays the highest and lowest yield cases for Maturity Group 4. Case #86 had a yield of 10.1 bushels per acre, while Case #100 had a yield of 55.3 bushels per acre. Case #100 was planted on April 20th, almost a month earlier than Case #86, which was planted on May 17th. Even though Case #100 was planted earlier, the two cases had similar growing season lengths, with Case #100 taking 125 days to reach full maturity, and Case #86 taking 123 days. However, the higher yielding case received much more precipitation throughout the growing season—15.37" as opposed to 9.52". Evaporative stress on the plant was noticeably less for the higher yielding soybeans than the lower Case #86 beans; the precipitation – evaporation total for the lower yield case was –17.58" as compared to –10.29" for Case #100. The higher yielding case also experienced lower average maximum temperatures and fewer +90 days, as well as fewer accumulated HTs than Case #86.

Table 19: Mature Group 4 Highest and Lowest Yield Cases

Case	Year	Yield	Sig. Dates	Month	Day	Period Type	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT
86	99	101	plant	5	17	P-B	32	4.28	9	7.6993	-3.4193	904	584	68.28125	88.21875	58
86	99	101	bloom	6	18	B-P	24	3.29	10	5.221701	-1.9317	745.5	505.5	72.41667	89.70833	62
86	99	101	podset	7	12	P-S	18	0.49	2	3.36	-2.87	591	411	72.44444	93.22222	64
86	99	101	seedform	7	30	S-F	28	0.23	2	6.432	-6.202	939.5	659.5	70.71429	96.39286	61
86	99	101	fullseed	8	27	F-M	21	1.23	3	4.384	-3.154	640.5	420.5	65.45455	92.77273	52
86	99	101	mature	9	17	Total	123	9.52	26	27.097	-17.577	3820.5	2580.5	69.86224	92.06298	52
100	00	553	plant	4	20	P-B	36	6.82	14	6.84	-0.02	780	422.5	61.66667	81.66667	48
100	00	553	bloom	5	26	B-P	25	4.35	6	5.664	-1.314	736	486	68.8	90.08	56
100	00	553	podset	6	20	P-S	13	2.5	4	2.32	0.18	396	266	71.92308	89	68
100	00	553	seedform	7	3	S-F	35	1.7	3	7.104	-5.404	1166	816	72.85714	93.77143	66
100	00	553	fullseed	8	7	F-M	16	0	0	3.736	-3.736	585	415	71.29412	97.52941	65
100	00	553	mature	8	23	Total	125	15.37	27	25.664	-10.294	3663	2405.5	69.3082	90.4095	48

Table 19 (continued)

AbsMaxT	AvgDayLn	+90 Days	85	86	87	88	89	90	91	92	93	94	95	96	97	98
94	14.05144	12	119	95	73	56	40	26	14	6	1	0	0	0	0	0
97	14.18117	13	121	101	82	63	47	32	19	10	5	3	2	1	0	0
100	13.90687	14	149	133	117	102	88	74	60	47	38	29	22	16	10	5
104	13.31245	26	319	291	263	236	210	184	158	133	109	86	66	47	33	21
99	12.49402	15	173	153	133	114	98	82	67	53	39	26	17	9	3	1
104	13.58919	80	881	773	668	571	483	398	318	249	192	144	107	73	46	27
93	13.51888	2	41	31	22	15	8	4	2	1	0	0	0	0	0	0
97	14.12999	16	152	131	110	91	73	56	40	26	13	7	3	1	0	0
94	14.21082	4	58	48	38	28	19	11	7	4	2	0	0	0	0	0
101	13.89545	27	308	275	243	212	182	154	127	102	78	56	38	25	16	10
103	13.24259	17	213	196	179	162	145	128	111	95	80	65	51	37	27	20
103	13.79955	66	772	681	592	508	427	353	287	228	173	128	92	63	43	30

Table 20 displays the highest and lowest yield cases for Maturity Group 5. Case #122 had a yield of 10.5 bushels per acre while Case #95 had 59.5 bushels per acre. Case #95 was planted on April 30, about two and a half weeks before Case #122, which was planted on May 17. The total growing season was shorter for the lower yielding soybeans, at 130 days as compared to 146 days for Case #95. The high yielding case received more precipitation spread out over more days throughout the growing season—15.26” in 40 precipitation days as opposed to 9.58” in 27 precipitation days for Case #122. The higher yielding case in Maturity Group 5 also experienced less evaporative stress than the lower yielding case; Case #95 P-E value was –13.00” as opposed to –18.94” for Case #122. The higher yielding case also experienced lower average and absolute maximum temperatures, as well as fewer +90 days and fewer accumulated HTs than Case #122.

From these descriptive statistics, it seemed that higher yields were associated overall with earlier planting dates, longer growing seasons, lower extreme high temperatures (average maximum temperature, absolute maximum temperature, and HTs), and more precipitation spread out over more precipitation days. Although the descriptive statistics pointed out possible pertinent relationships, descriptive statistics alone were not enough to determine definitively which weather variables might be influencing yield. In addition to this, the descriptive statistics failed to show in which period certain weather variables might have an influence on yield.

Table 20: Mature Group 5 Highest and Lowest Yield Cases

Case	Year	Yield	Sig. Dates	Month	Day	Period Type	# of days	totP	Pdays	.8PE	P-E	DD50	DD60	AvgMinT	AvgMaxT	AbsMinT
122	99	105	plant	5	17	P-B	49	7.4	15	11.577	-4.177	1415.5	925.5	69.53061	88.2449	58
122	99	105	bloom	7	5	B-P	14	0.24	5	2.544	-2.304	434	294	71.14286	90.85714	64
122	99	105	podset	7	19	P-S	18	0.42	1	3.64	-3.22	638.5	458.5	74.38889	96.55556	69
122	99	105	seedform	8	6	S-F	28	0.81	3	6.616	-5.806	918	638	69.42857	96.14286	61
122	99	105	fullseed	9	3	F-M	21	0.71	3	4.144	-3.434	552.5	332.5	61	89.22727	45
122	99	105	mature	9	24	**Total**	**130**	**9.58**	**27**	**28.521**	**-18.941**	**3958.5**	**2648.5**	**69.09819**	**92.20555**	**45**
95	96	595	plant	4	30	P-B	52	5.7	11	11.08886	-5.38886	1399	886	67.01923	86.78846	43
95	96	595	bloom	6	21	B-P	24	0.28	3	5.224	-4.944	789.5	549.5	73.08333	92.70833	65
95	96	595	podset	7	15	P-S	18	3.87	11	3.448	0.422	570.5	390.5	72.66667	90.72222	69
95	96	595	seedform	8	2	S-F	38	3.82	13	6.108	-2.288	1091.5	711.5	68.94737	88.5	61
95	96	595	fullseed	9	9	F-M	14	1.59	2	2.392	-0.802	353	203	62.4	84.66667	55
95	96	595	mature	9	23	**Total**	**146**	**15.26**	**40**	**28.26086**	**-13.0009**	**4203.5**	**2740.5**	**68.82332**	**88.67714**	**43**

Table 20 (continued)

AbsMaxT	AvgDayLn	+90 Days	85	86	87	88	89	90	91	92	93	94	95	96	97	98
94	14.10543	18	183	146	112	83	58	36	18	8	2	0	0	0	0	0
97	14.06697	10	83	71	59	48	38	28	18	8	4	3	2	1	0	0
100	13.75306	18	208	190	172	154	136	118	100	83	67	51	38	27	18	10
104	13.09617	26	312	284	256	229	203	177	151	126	102	79	60	41	26	16
99	12.24812	10	115	99	83	68	56	45	35	26	17	11	7	4	2	1
104	**13.45395**	82	901	790	682	582	491	404	322	251	192	144	107	73	46	27
96	13.89703	16	197	163	130	100	73	51	35	23	13	6	2	0	0	0
97	14.15952	18	185	161	137	114	92	72	54	36	23	13	5	2	0	0
98	13.84412	10	107	91	76	61	47	37	27	19	12	8	5	3	1	0
96	13.05788	17	165	134	108	87	67	48	31	15	6	3	1	0	0	0
93	12.15995	3	35	28	21	16	11	6	3	1	0	0	0	0	0	0
98	**13.4237**	64	689	577	472	378	290	214	150	94	54	30	13	5	1	0

Correlation Analyses

In order to determine which of the variables (any of the weather variables or phenological period length) were influencing yield, correlation analyses and significance tests were conducted to try to determine which of the variables were strongly related to soybean yield. The spreadsheets containing the soybean and weather data were imported into a statistics software program called Statistical Package for the Social Sciences (SPSS). Once the data were entered into SPSS, correlation analyses were performed in order to determine the strength of the relationship between a given variable and soybean yield. Each phenological period in each maturity group was tested separately, in addition to testing each maturity group as a whole. Along with the correlation coefficients, the significance of the relationships was determined. Tables 21 and 22 display the results of the correlation analyses for both Maturity Group 4 and Maturity Group 5.

In Table 21 for Maturity Group 4, the results of the correlation analysis are displayed for the soybean cases overall (called “total), as well as broken down by phenological period. Correlation coefficients are ordered by the strength of the correlation, and the significance of the relationship is denoted by either a * for significance at the P= 0.05 level, or a ** for significance at the P=0.01 level. For the total of Mature Group 4, the two weather variables that influenced yield the most were average maximum temperature and absolute maximum temperature. Average maximum temperature had a correlation coefficient of –0.596 (which was

Table 21: Mature Group 4 Correlation Coefficients and Significance Levels

Total	Correlation factor and Significance
AvgMaxT	-0.596**
AbsMaxT	-0.593**
HT 95	-0.579**
HT 96	-0.575**
HT 94	-0.572**
P Days	0.567**
HT 93	-0.563**
HT 92	-0.557**
HT 97	-0.556**
HT 90	-0.548**
HT 91	-0.545**
HT 89	-0.542**
HT 88	-0.536**
P-E	0.532**
HT 87	-0.531**
HT 98	-0.530**
HT 85	-0.519**
Total P	0.512**
HT 86	-0.496**
+90 Days	-0.445**
AvgMinT	-0.413**
PltDate	-0.413**
AbsMinT	-0.393**
# days tot	0.318**
DD60	-0.229*

P-B	Correlation factor and Significance
AbsMinT	-0.520**
# Days	0.437**
AvgMinT	-0.378**
AvgMaxT	-0.355**
AvgDayLn	-0.354**
.8PE	0.296**
HT 97	-0.226*
HT 98	-0.226*
AbsMaxT	-0.207*
Total P	0.194*
P Days	0.188*

B-P	Correlation factor and Significance
None	None

P-S	Correlation factor and Significance
P Days	0.412**
AbsMaxT	-0.365**
Total P	0.348**
HT 95	-0.317**
HT 96	-0.315**
HT 97	-0.303**
HT 94	-0.295**
HT 93	-0.287**
HT 98	-0.266**
P-E	0.262**
.8PE	0.256**
HT 92	-0.252**
# Days	0.231*
AvgMaxT	-0.229*
HT 91	-0.217*
HT 90	-0.194*
AbsMinT	-0.190*

S-F	Correlation factor and Significance
HT 95	-0.578**
HT 94	-0.578**
HT 93	-0.574**
HT 96	-0.571**
HT 92	-0.567**
HT 97	-0.559**
HT 91	-0.558**
HT 98	-0.546**
HT 90	-0.542**
AvgMaxT	-0.537**
HT 89	-0.525**
HT 88	-0.510**
HT 87	-0.496**
AbsMaxT	-0.494**
HT 86	-0.482**
HT 85	-0.468**
P Days	0.467**
P-E	0.458**
Total P	0.447**
+90 Days	-0.337**

F-M	Correlation factor and Significance
HT 95	-0.391**
HT 96	-0.390**
HT 94	-0.388**
HT 93	-0.387**
HT 92	-0.386**
HT 98	-0.386**
HT 97	-0.382**
HT 91	-0.377**
AbsMaxT	-0.366**
HT 90	-0.365**
HT 89	-0.354**
HT 88	-0.344**
HT 87	-0.337**
HT 86	-0.330**
HT 85	-0.323**
AvgDayLn	0.290**
AvgMaxT	-0.338*
.8PE	-0.191*
+90 Days	-0.187*

** Highly Significant at the 0.01 Level
* Significant at the 0.05 Level

highly significant at the 0.01 level), which indicates that the higher the average maximum temperature was during the growing season, the lower the resultant yield (or the lower the average maximum temperature, the higher the yield). Absolute maximum temperature had a correlation coefficient of –0.593 (also highly significant), which shows that the higher the absolute maximum temperature, the lower the yield (or the lower the absolute maximum temperature, the higher the yield. Figures 14 and 15 display the scatter plots for these two variables that visually demonstrate the relationship between the high temperatures and yield (line represents the trendline for the data).

Other temperature variables, such as HT 95, HT 96, HT 94, were also significantly correlated to yield, with correlation coefficients of –0.579, -0.575, and –0.572, respectively. These values also indicate that the more HTs accrued (the more hotter it was), the lower the resultant yield. Figures 16, 17, and 18 are the scatter plots that were created to show the relationship between the HT variables and yield. These graphs show that the more HTs accrued, the lower the resultant yields.

Although correlation analysis showed that overall energy variables seemed to be affecting soybean yield the most, the moisture variables were important to yield as well. The number of precipitation days had a correlation coefficient of 0.567, which was highly significant and indicates that higher yields were associated with more precipitation days. Figure 19 displays the scatter plot for this variable and visually shows the relationship between higher yields and more precipitation

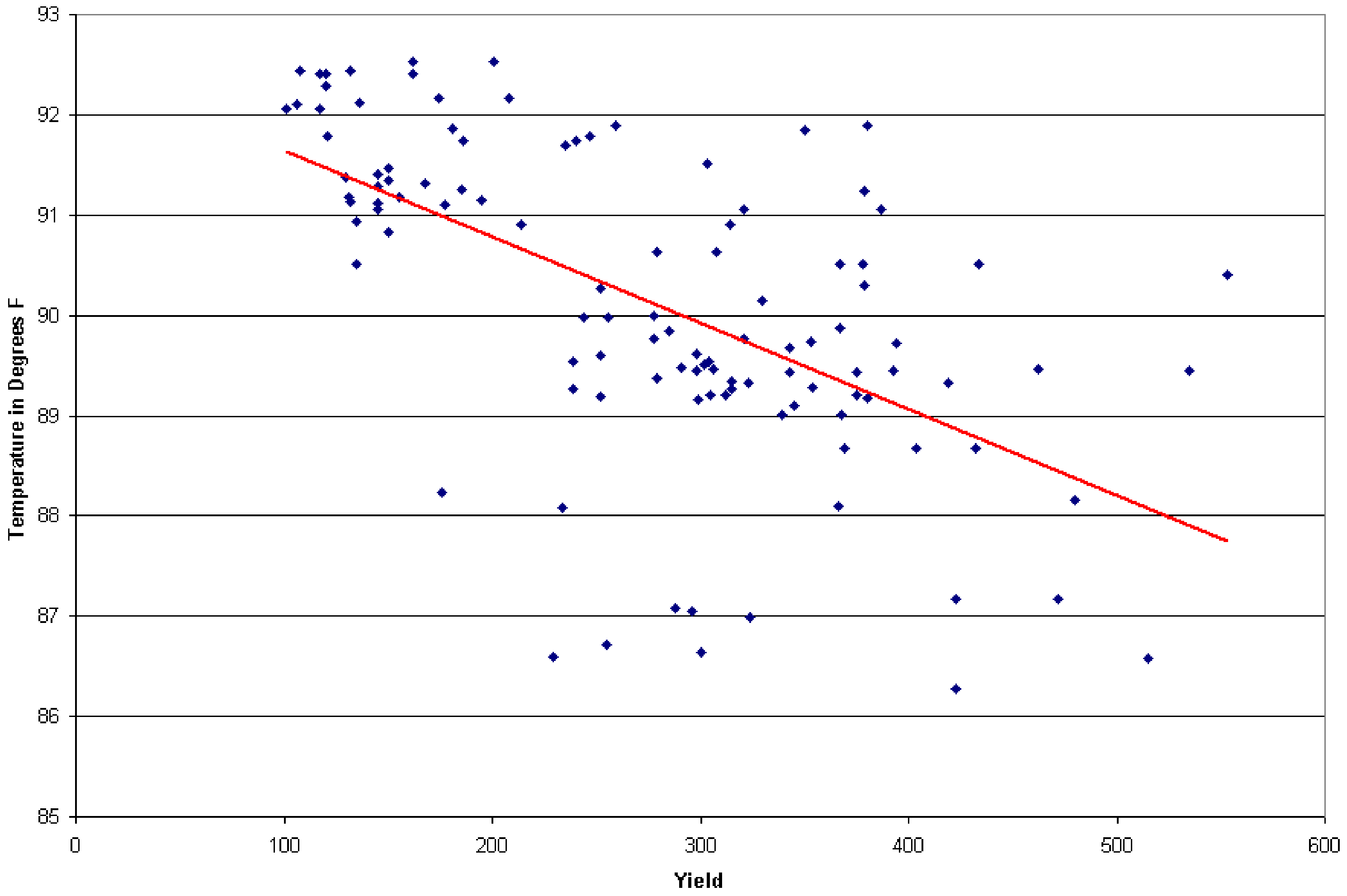


Figure 14: Mature Group 4 Yield versus Average Maximum Temperature for Total Growing Period

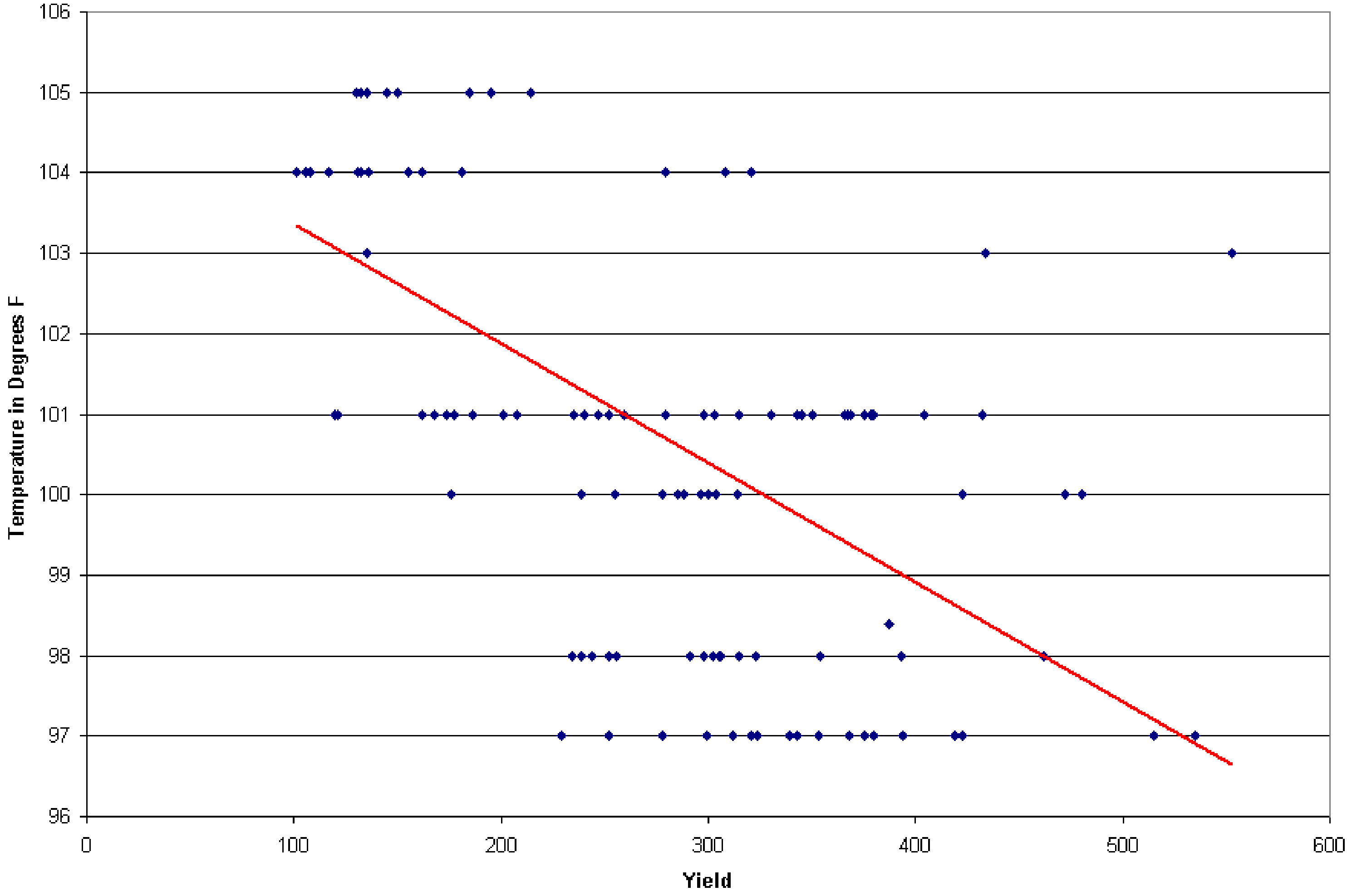


Figure 15: Mature Group 4 Yield versus Absolute Maximum Temperature for Total Growing Period

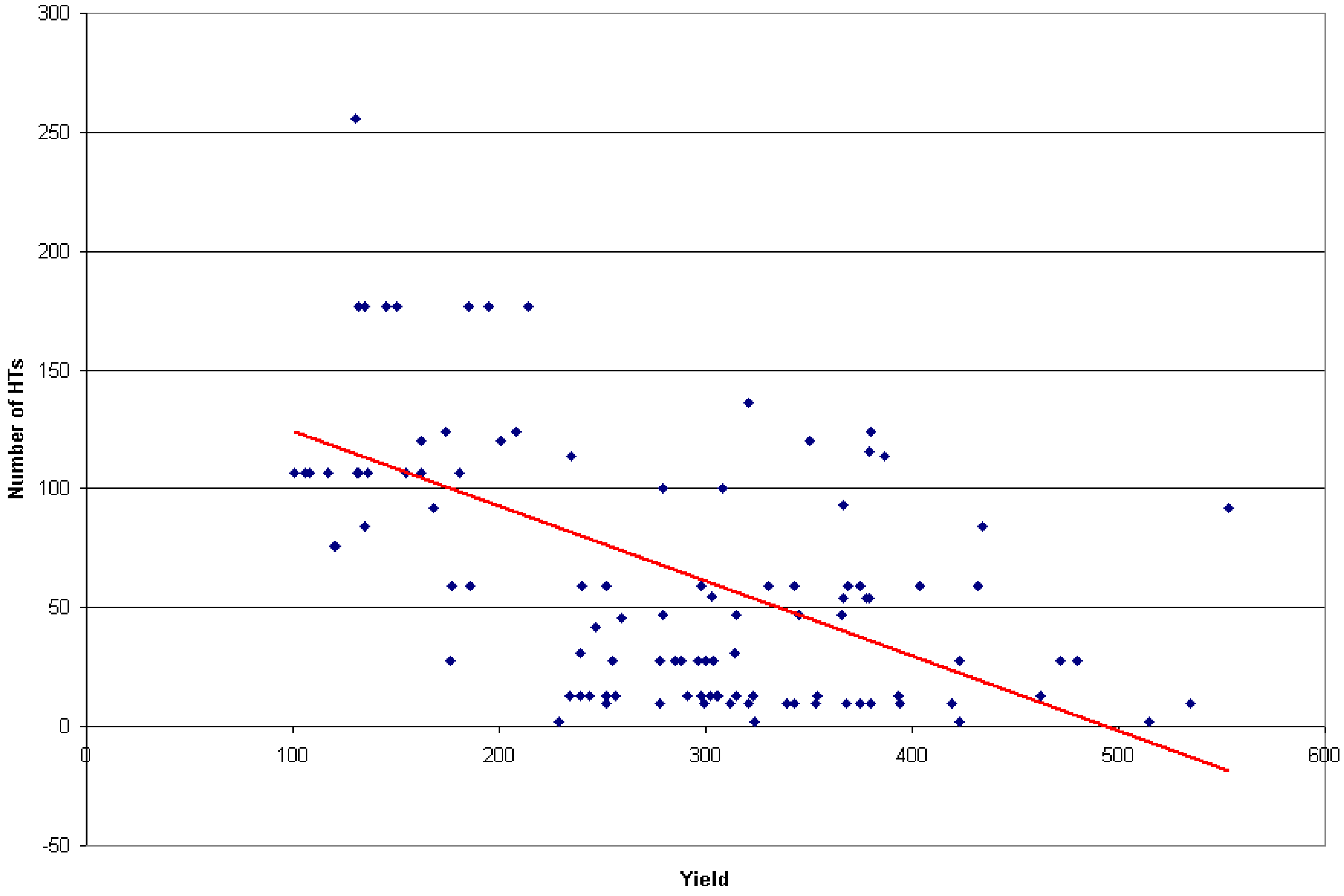
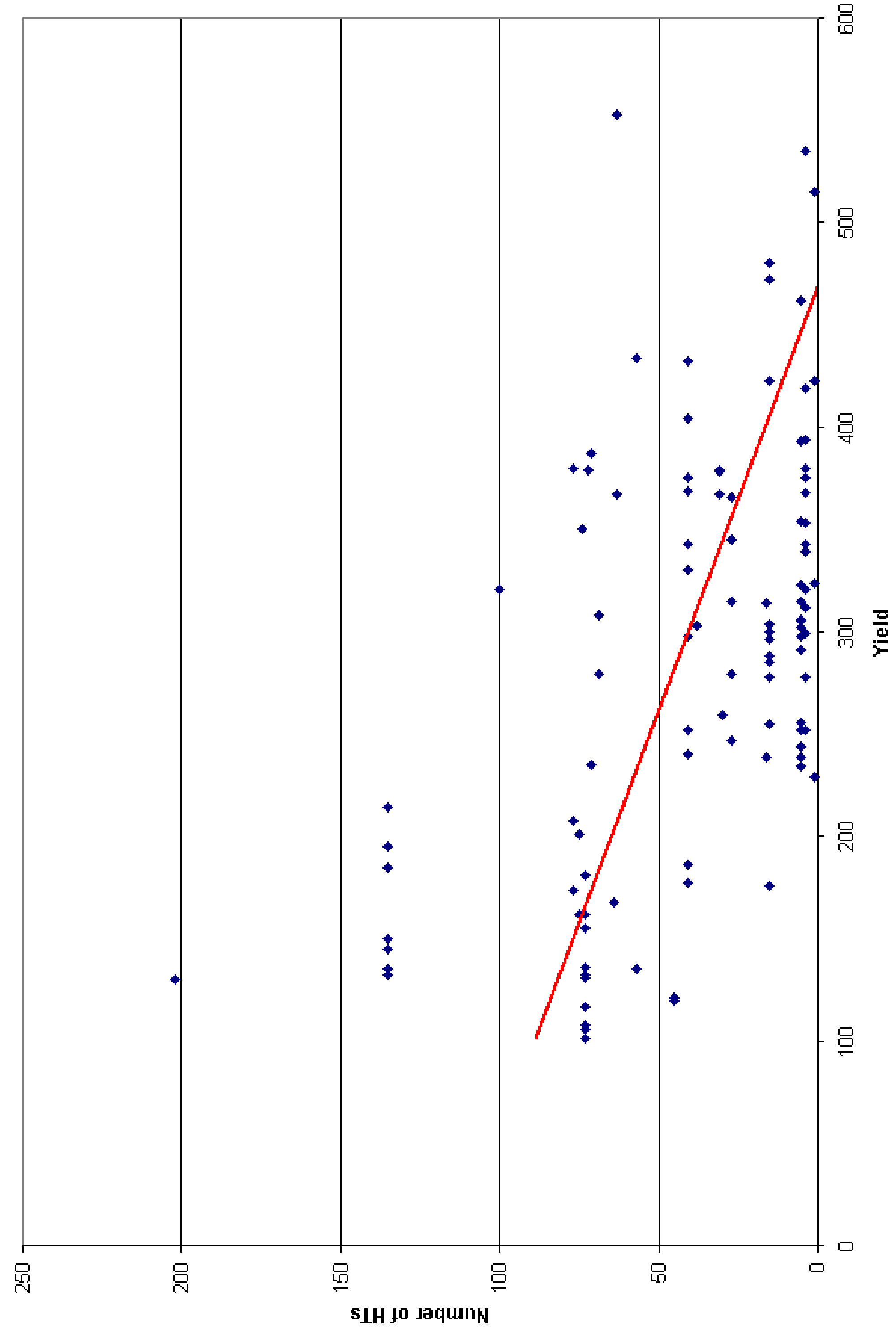
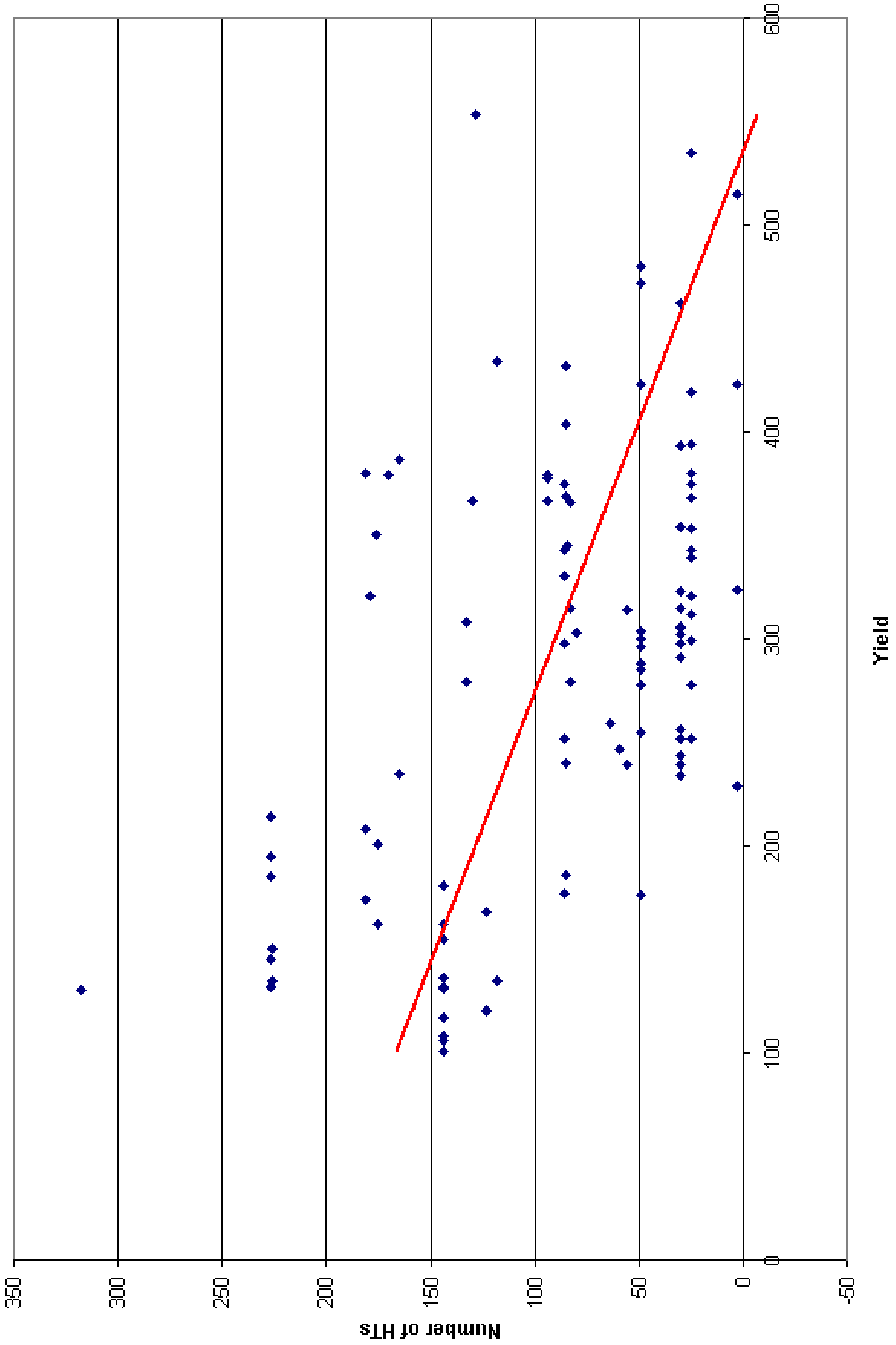


Figure 16: Mature Group 4 Yield versus HT 95s for Total Growing Period


Number of HTs
0
50
100
150
200
250
Yield
0
100
200
300
400
500
600


Number of HTs
350
300
250
200
150
100
50
0
-50
Yield
0
100
200
300
400
500
600

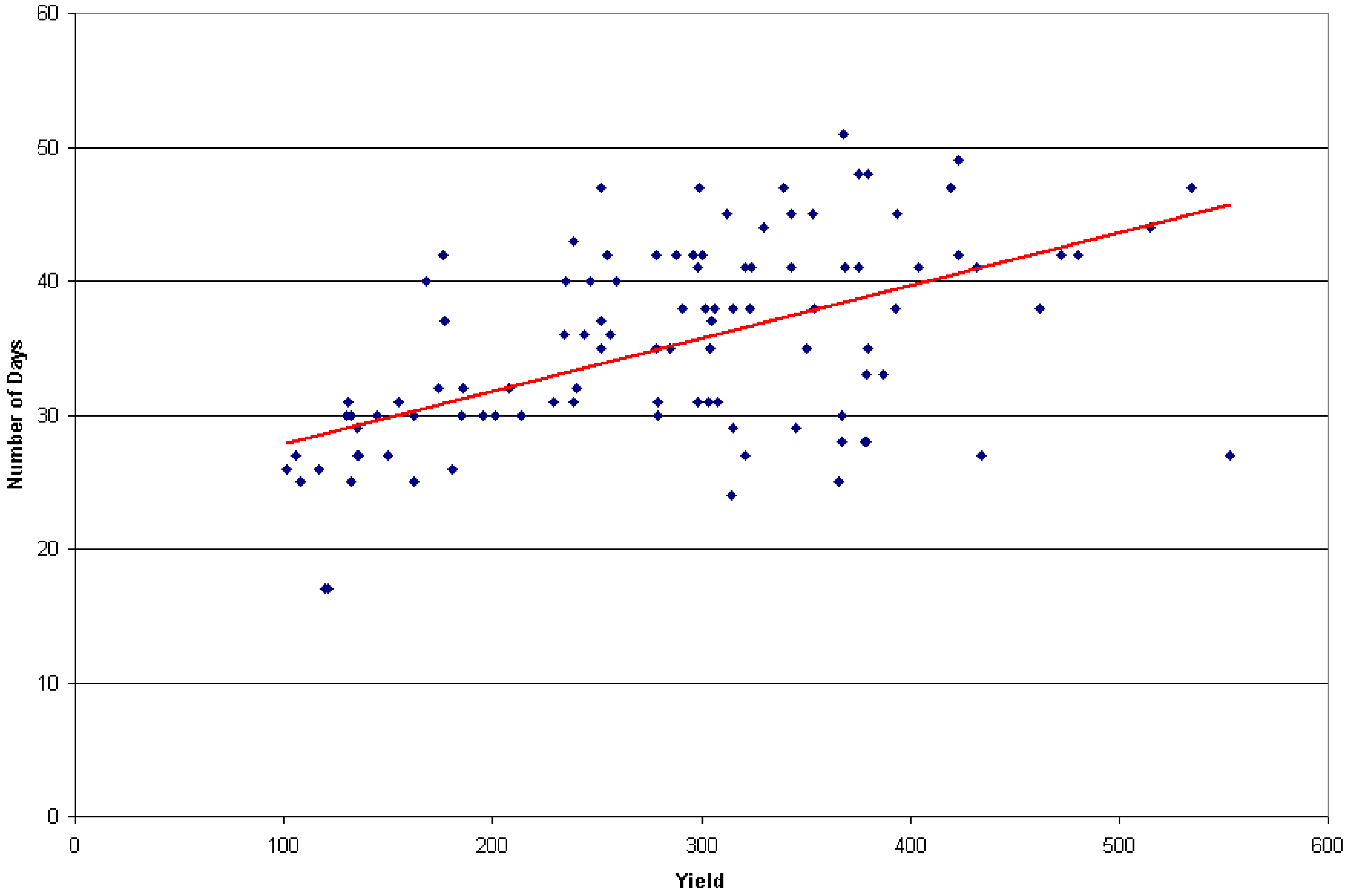
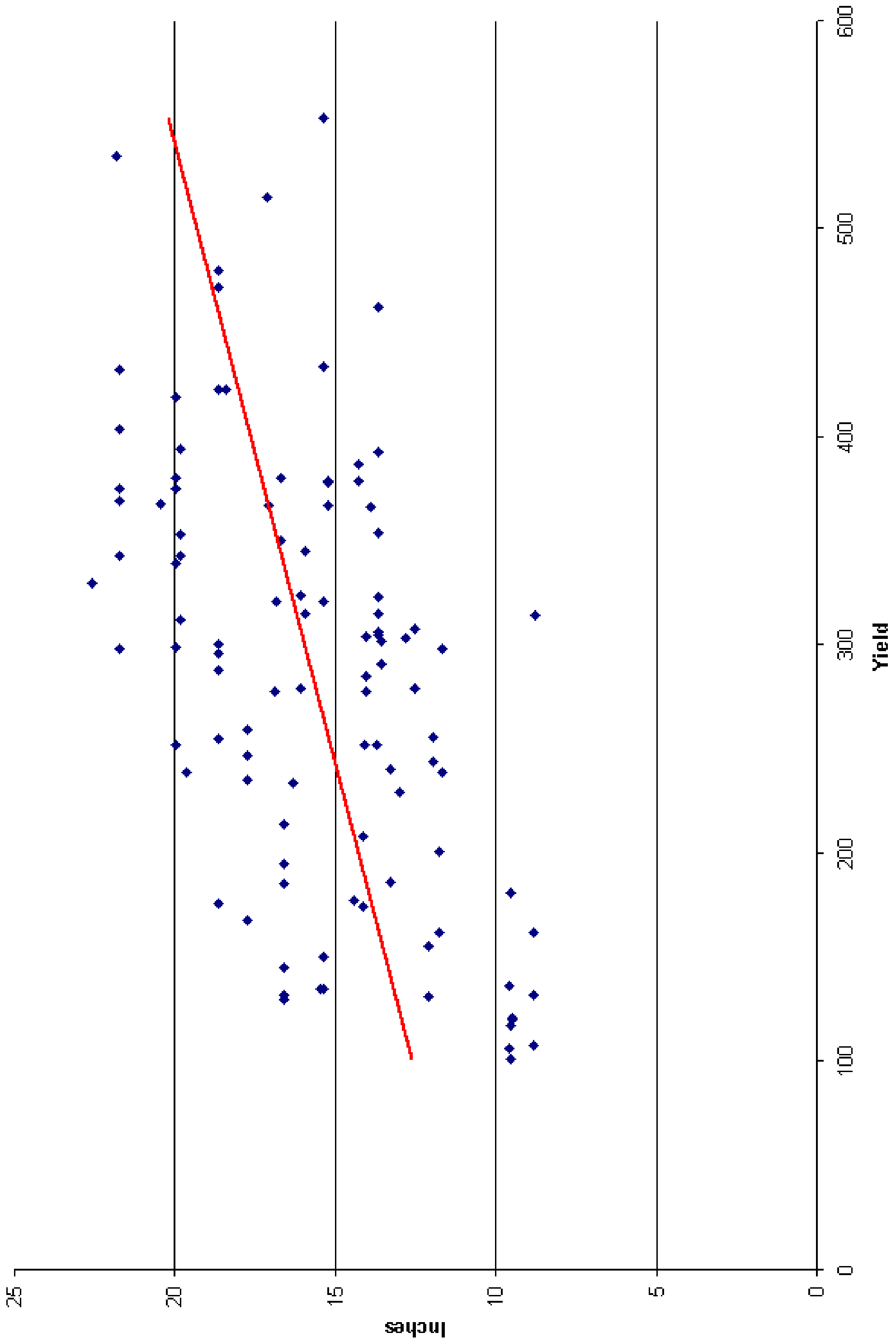


Figure 19: Yield versus the Number of Precipitation Days for Total Growing Period

days. Total precipitation was also highly significant with a correlation coefficient of 0.512, which shows that higher precipitation resulted in a higher yield, as shown in the scatter plot in Figure 20. Precipitation – evaporation (P-E) was also highly significant with a correlation value of 0.532, indicating that the plants that experienced less evaporative stress had a higher yield. This relationship is also shown in Figure 21, a scatter plot of the P-E variable that demonstrates that the less evaporative stress the soybean incurred (whether due to more rainfall or cooler temperatures), the higher the yield.

In addition to the weather variables, the number of days in the total growing period was also found to be highly significant. For Mature Group 4, the correlation coefficient for number of days in the growing season versus yield was 0.318, which indicates that the longer the growing season, the higher the yield. Figure 22 shows a scatter plot of yield versus the total number of days in the growing season, and graphically displays that the longer growing seasons were associated with higher yields.

In addition to the total results, Table 21 also displays those variables that affected soybean yield during each of the phenological periods. These correlation analyses attempted to determine which of the variables affected the overall yield during each of the phenological periods. In the plant to bloom (P-B) period for Mature Group 4, the absolute minimum temperature variable most strongly correlated with yield, with a highly significant correlation coefficient of –0.520, which indicates that the lower the absolute minimum temperature was, the higher


Inches
Yield
0
5
10
15
20
25
0
100
200
300
400
500
600

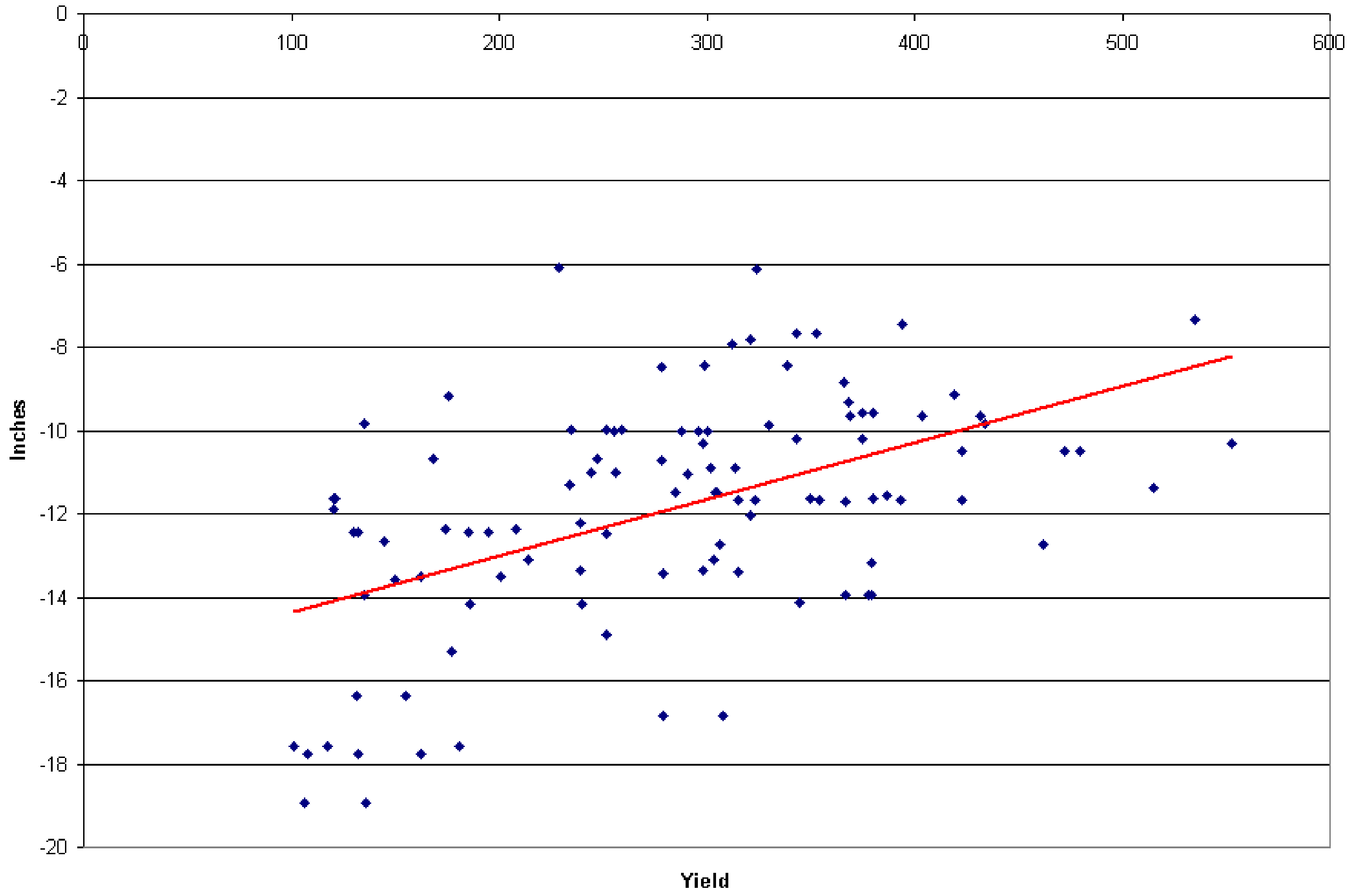


Figure 21: Yield versus P-E for Total Growing Period

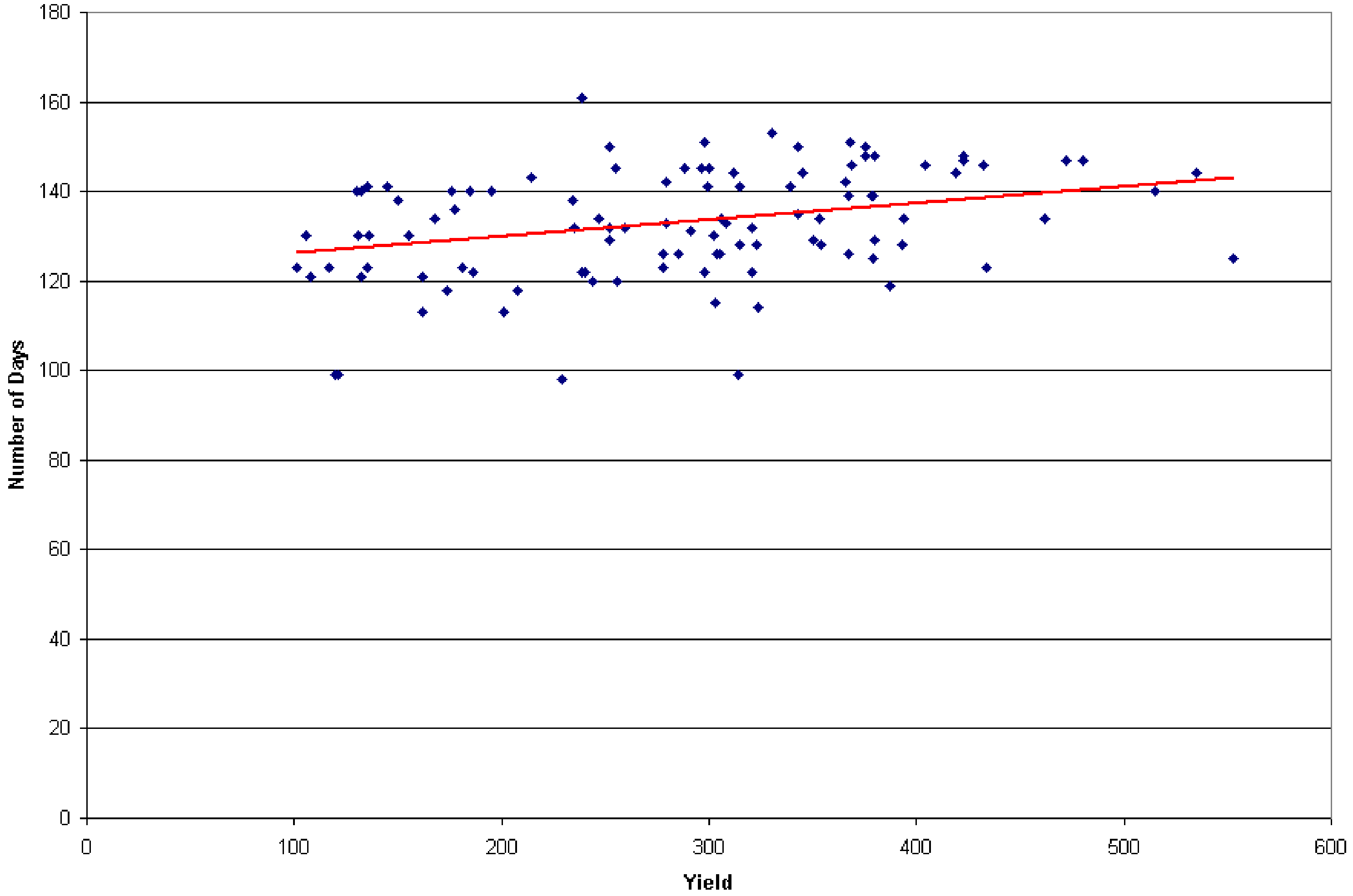


Figure 22: Mature Group 4 Yield versus the Number of Days for the Total Growing Period

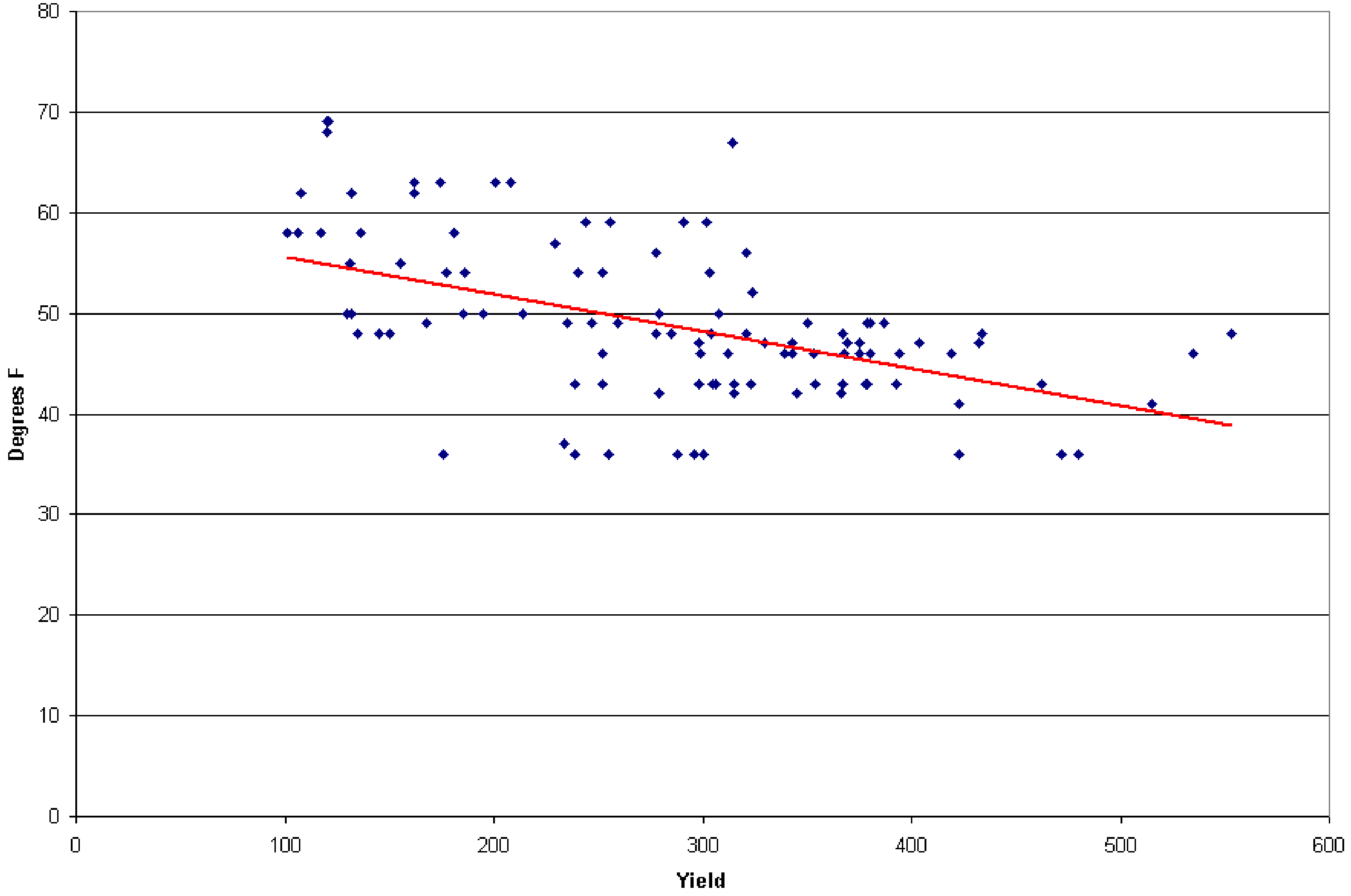


Figure 23: Mature Group 4 Yield versus the Absolute Minimum Temperature for the Plant – Bloom Period

the yield. Figure 23, a scatter plot of the absolute minimum temperature variable versus yield, demonstrates this relationship between the absolute minimum temperature in the plant to bloom period and yield. Also important to the overall yield in the plant to bloom period was the number of days in the P-B period. This variable was highly significant with a correlation coefficient of 0.437, indicating that the longer the P-B period was, the higher the yield. Figure 24 graphically displays that the longer P-B periods were associated with higher yields. Average maximum temperature was also highly significant, with a correlation coefficient of –0.355, again indicating that higher yield were associated with lower average maximum temperatures in the P-B period. Figure 25, a scatter plot of the average maximum temperature with yield, shows the relationship between the lower average maximum temperatures in the P-B period and higher yields. The precipitation variables were not as highly significant to yield in the plant to bloom period—total precipitation had a coefficient of 0.194, and the number of precipitation days had a coefficient of 0.188. P-E was not significant at all in the plant to bloom period. Figures 26 and 27 show the marginal relationship between yield and the precipitation variables in the plant to bloom period.

For Mature Group 4 in the bloom to podset period, none of the variables were strongly correlated to yield or were highly significant. However, in the podset to seedform period, all three of the precipitation variables, the number of precipitation days, total precipitation, and precipitation – evaporation were highly significant to yield. The number of precipitation days had a correlation coefficient

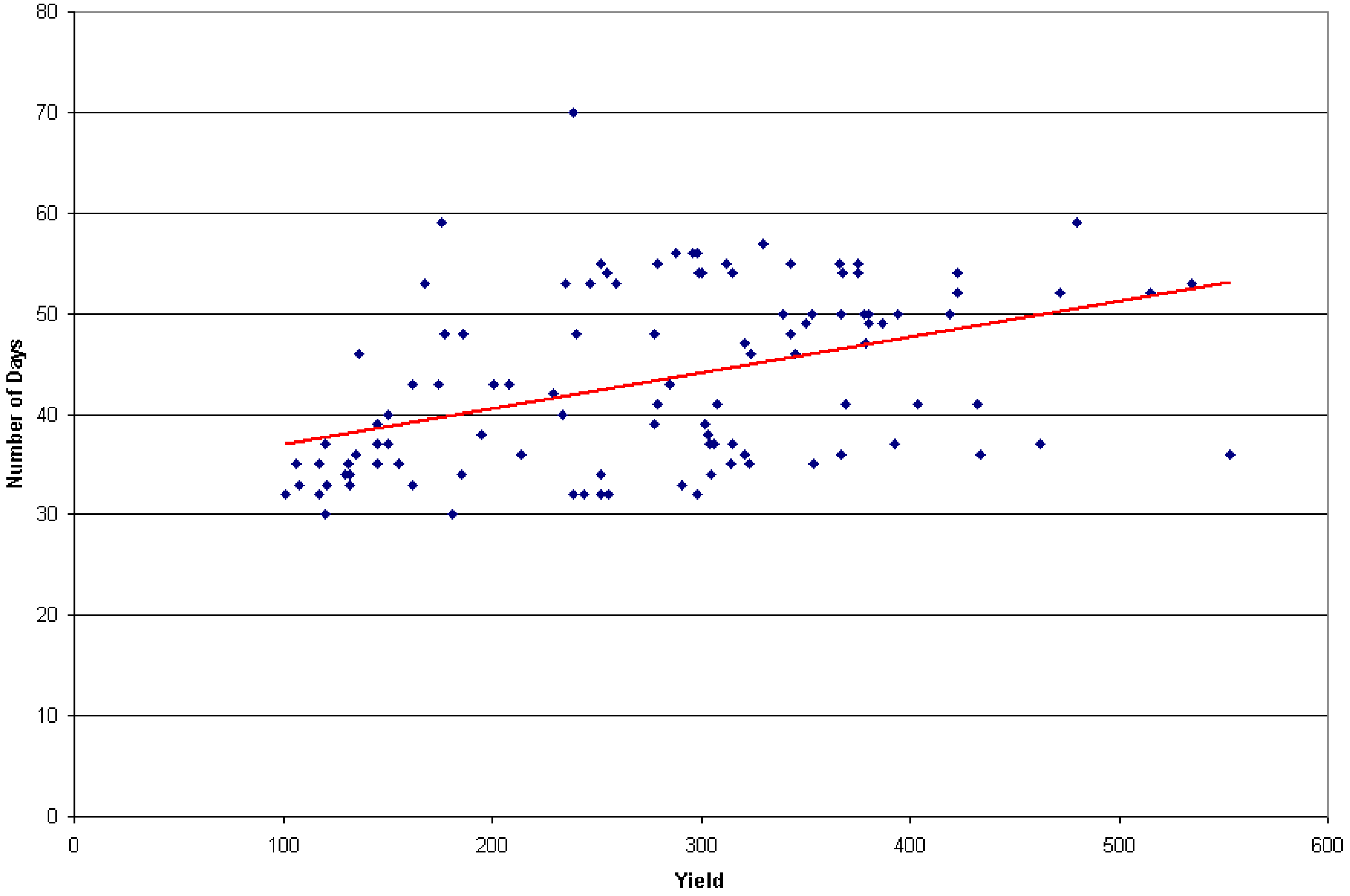


Figure 24: Mature Group 4 Yield versus the Number of Days in the Plant – Bloom Period

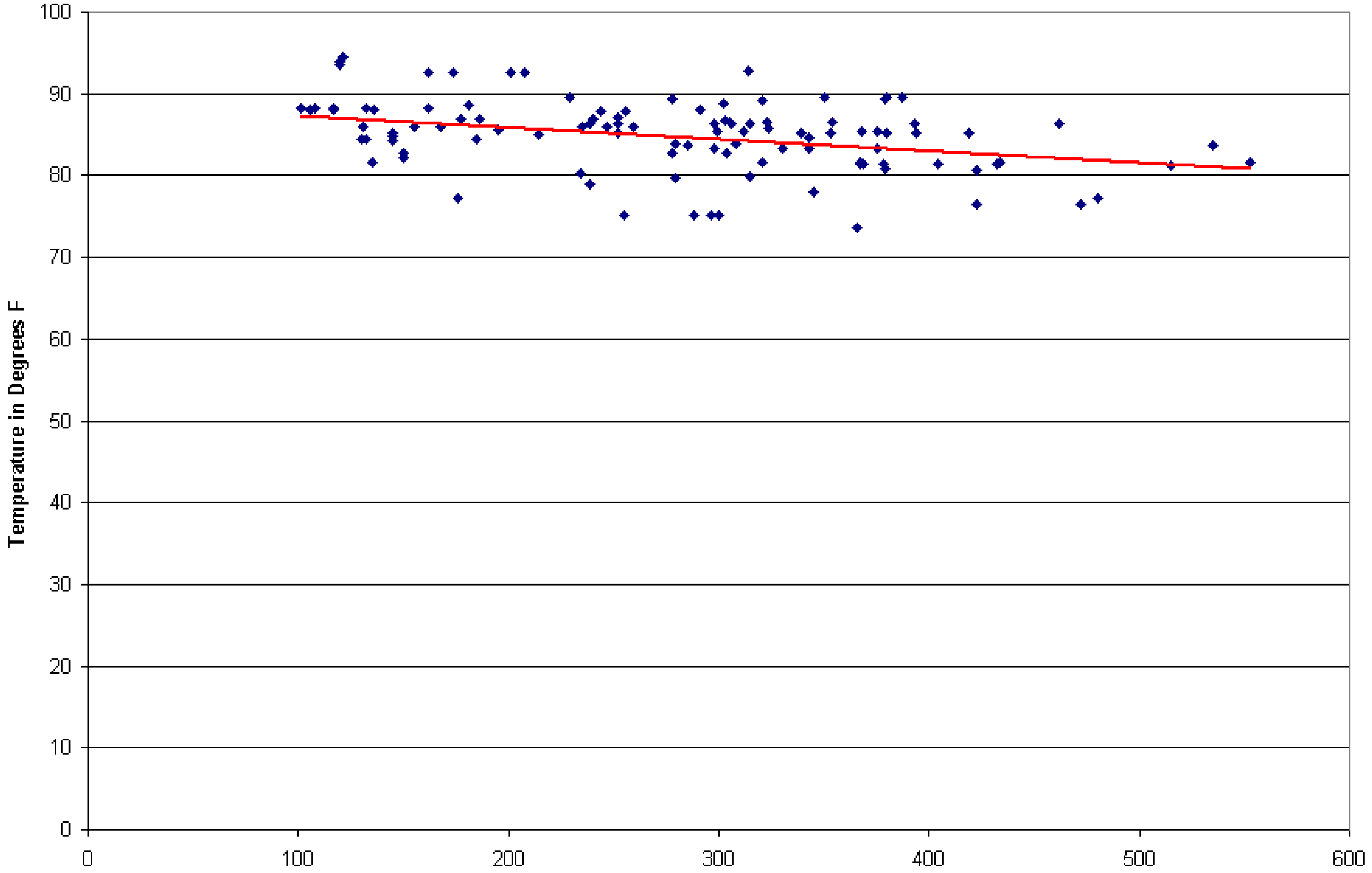


Figure 25: Mature Group 4 Yield versus the Average Maximum Temperature for the Plant – Bloom Period

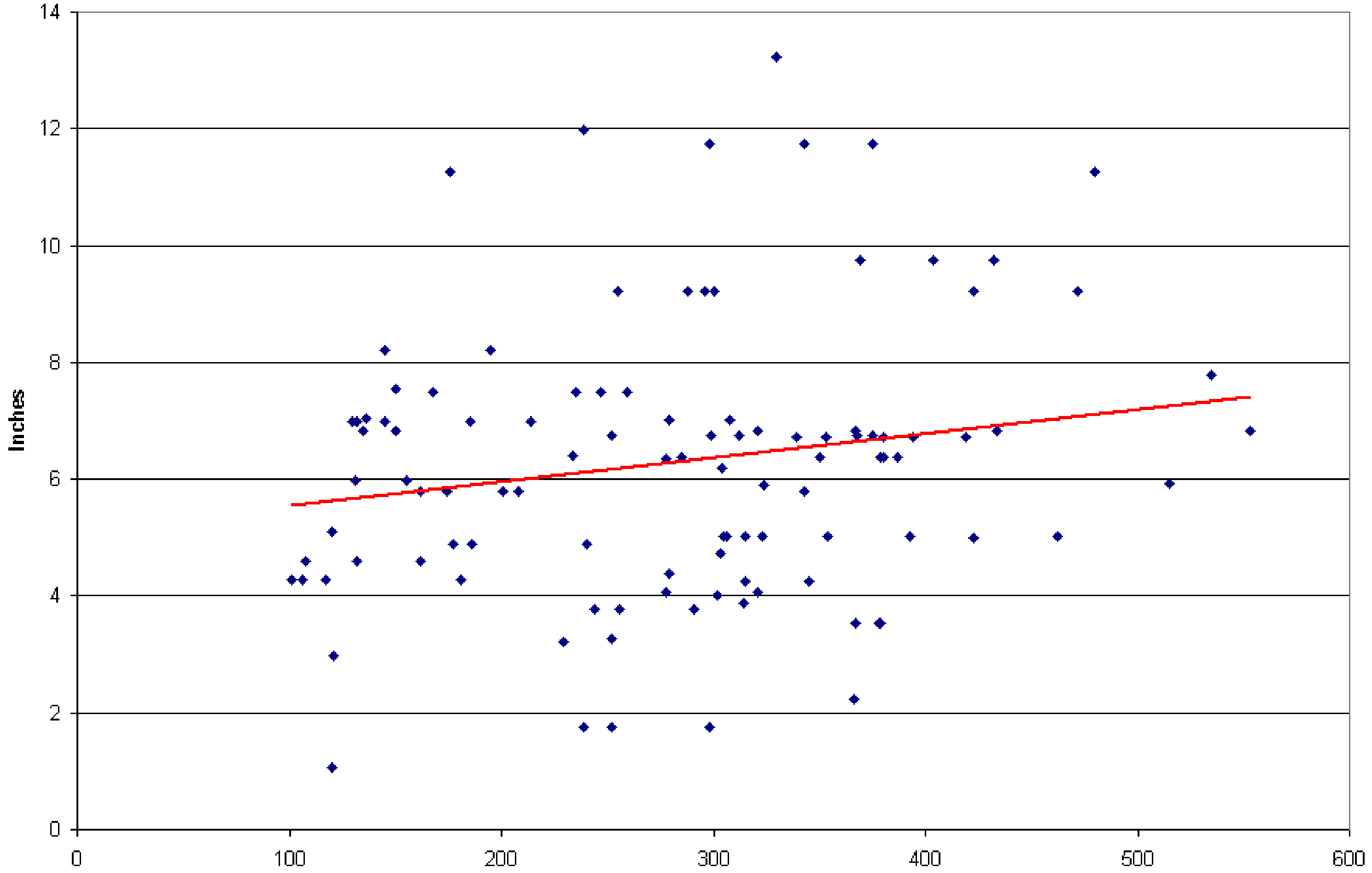


Figure 26: Mature Group 4 Yield versus Precipitation in the Plant – Bloom Period

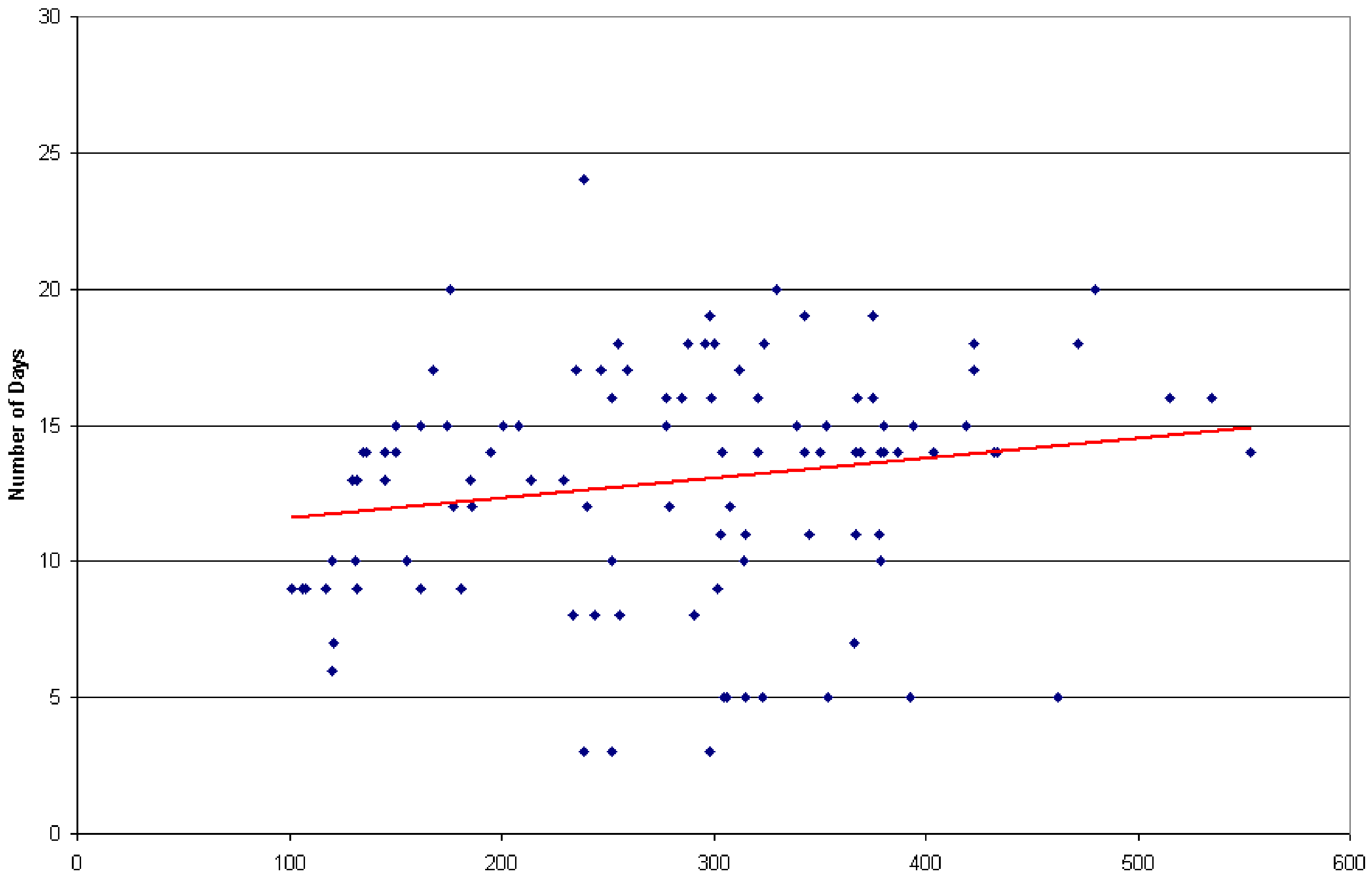


Figure 27: Mature Group 4 Yield versus the Number of Precipitation Days for the Plant – Bloom Period

of 0.412, total precipitation had a value of 0.348, and P-E had a value of 0.262, all indicating that the wetter it was during the P-S period the higher the yield. Figures 28, 29, and 30 graphically display the results of the scatter plots that were created to show the relationship between higher moisture values and higher yields. In addition to the precipitation variables being important to yield in the P-S period, the absolute maximum temperature was also strongly correlated to yield with high significance. Absolute maximum temperature had a correlation value of –0.365, indicating that the higher the maximum temperature was in the P-S period, the lower the yield. Figure 31 shows the relationship between lower absolute maximum temperatures and higher yield.

During the seedform to fullseed period for Mature Group 4, the energy variables were the ones that most influenced yield, as Table 21 shows. The higher HT variables, such as HT 95, were most strongly correlated with influencing yield. HT 95 had a correlation coefficient of –0.578, which was highly significant and showed that higher temperatures caused lower yields. Figure 32 shows the relationship between fewer HT 95s and higher yield. The average maximum temperature was also strongly correlated to yield, with a coefficient of –0.537, which also indicates that lower yield were associated with higher average maximum temperatures. Figure 33 shows this relationship. Although energy variables were important to yield in the S-F period, the water variables also were highly significant and correlated strongly to yield. The number of precipitation days, P-E, and total

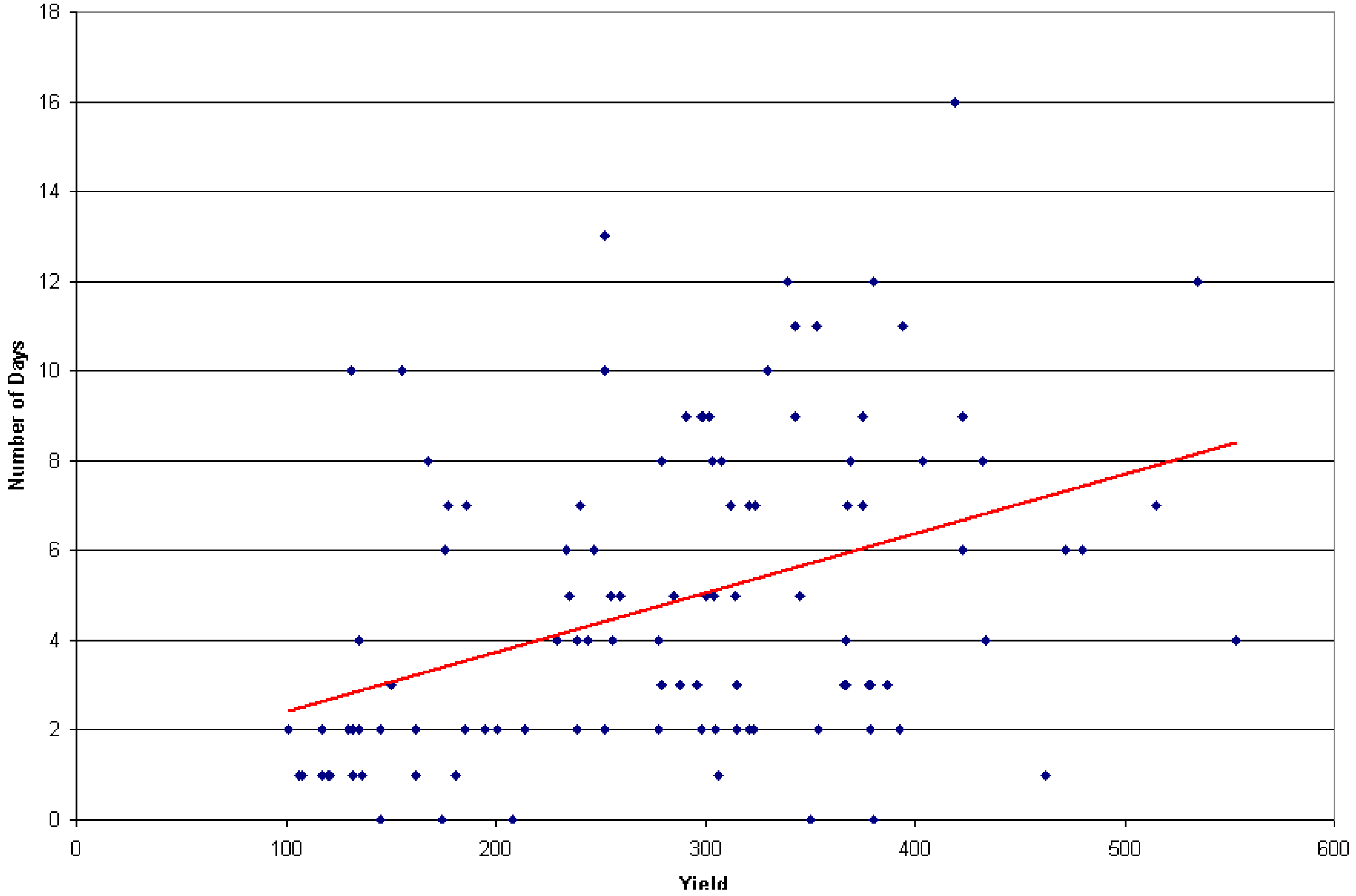


Figure 28: Mature Group 4 Yield versus the Number of Precipitation Days in the Podset – Seedform Period

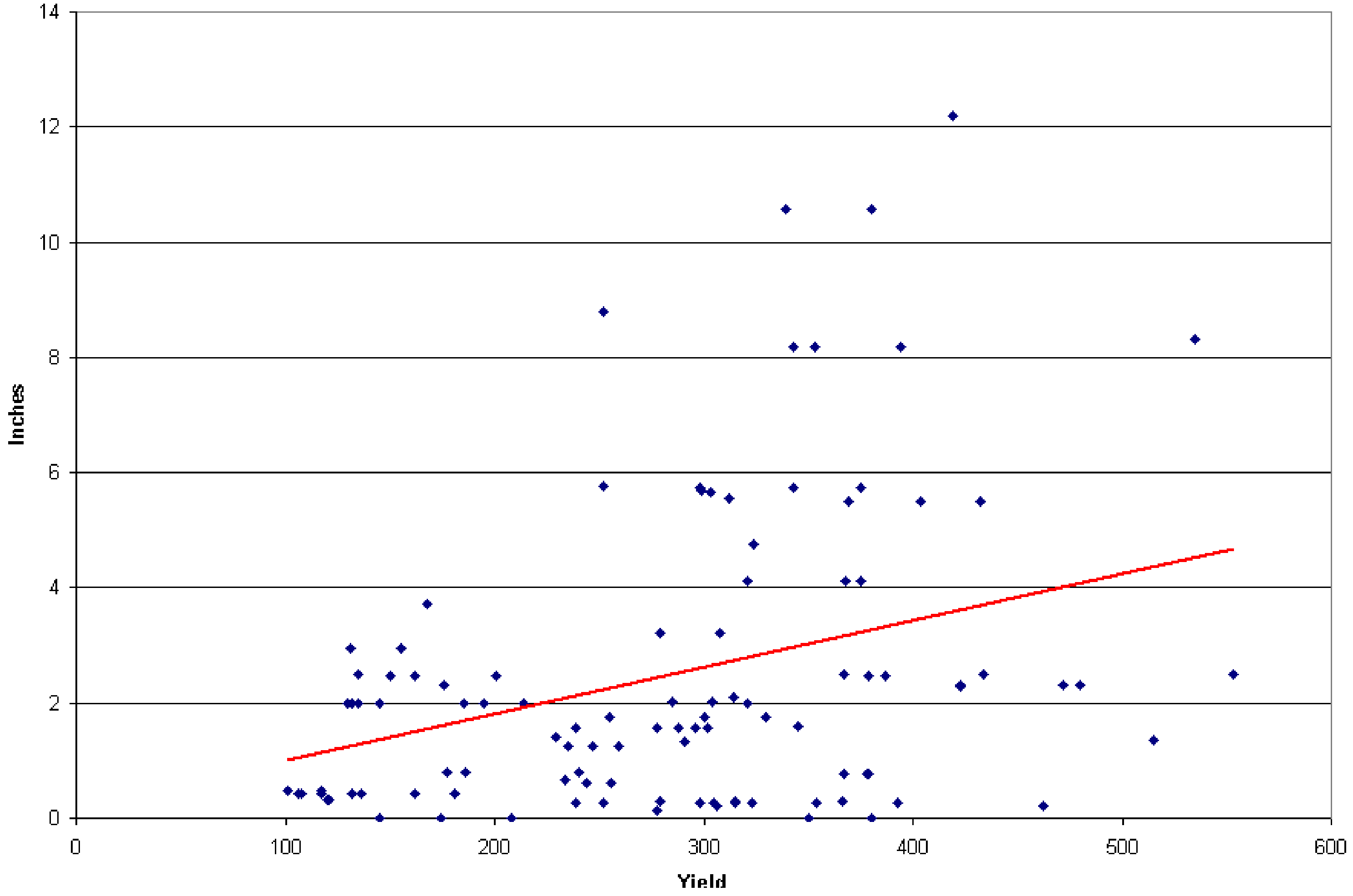


Figure 29: Mature Group 4 Yield versus Precipitation in the Podset – Seedform Period

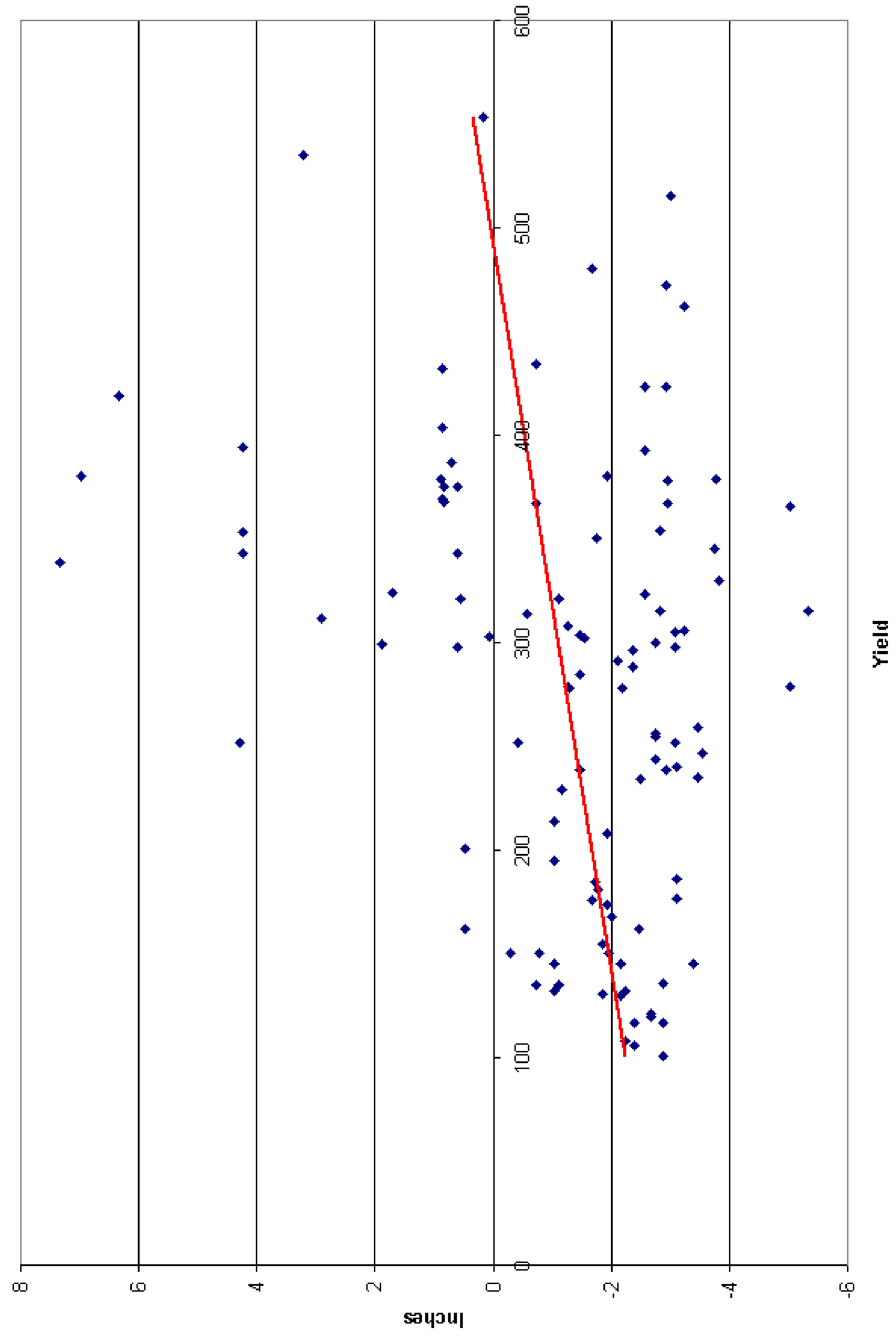


Figure 30: Mature Group 4 Yield versus P – E in the Podset – Seedform Period

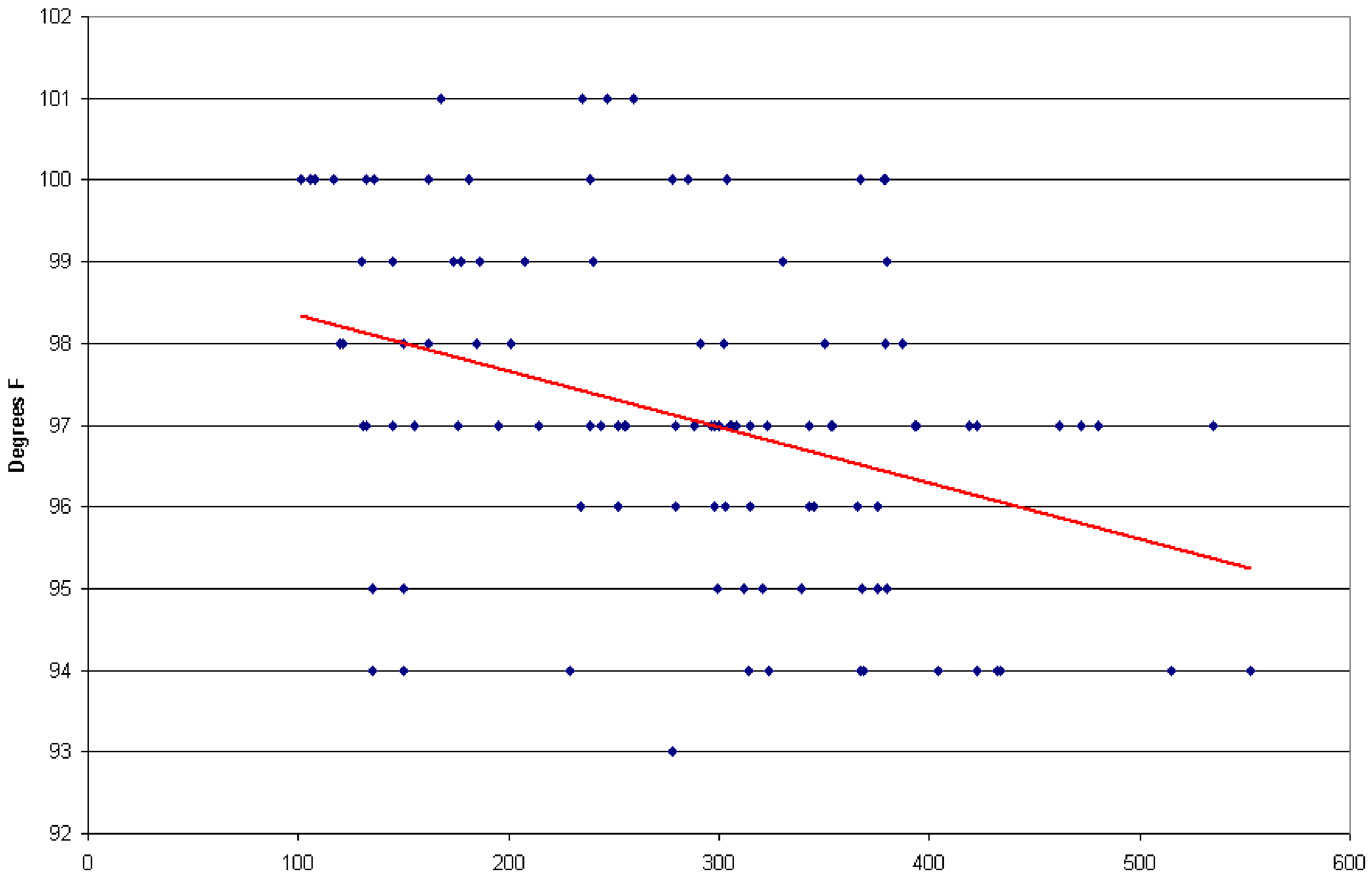


Figure 31: Mature Group 4 Yield versus the Absolute Maximum Temperature in the Podset – Seedform Period

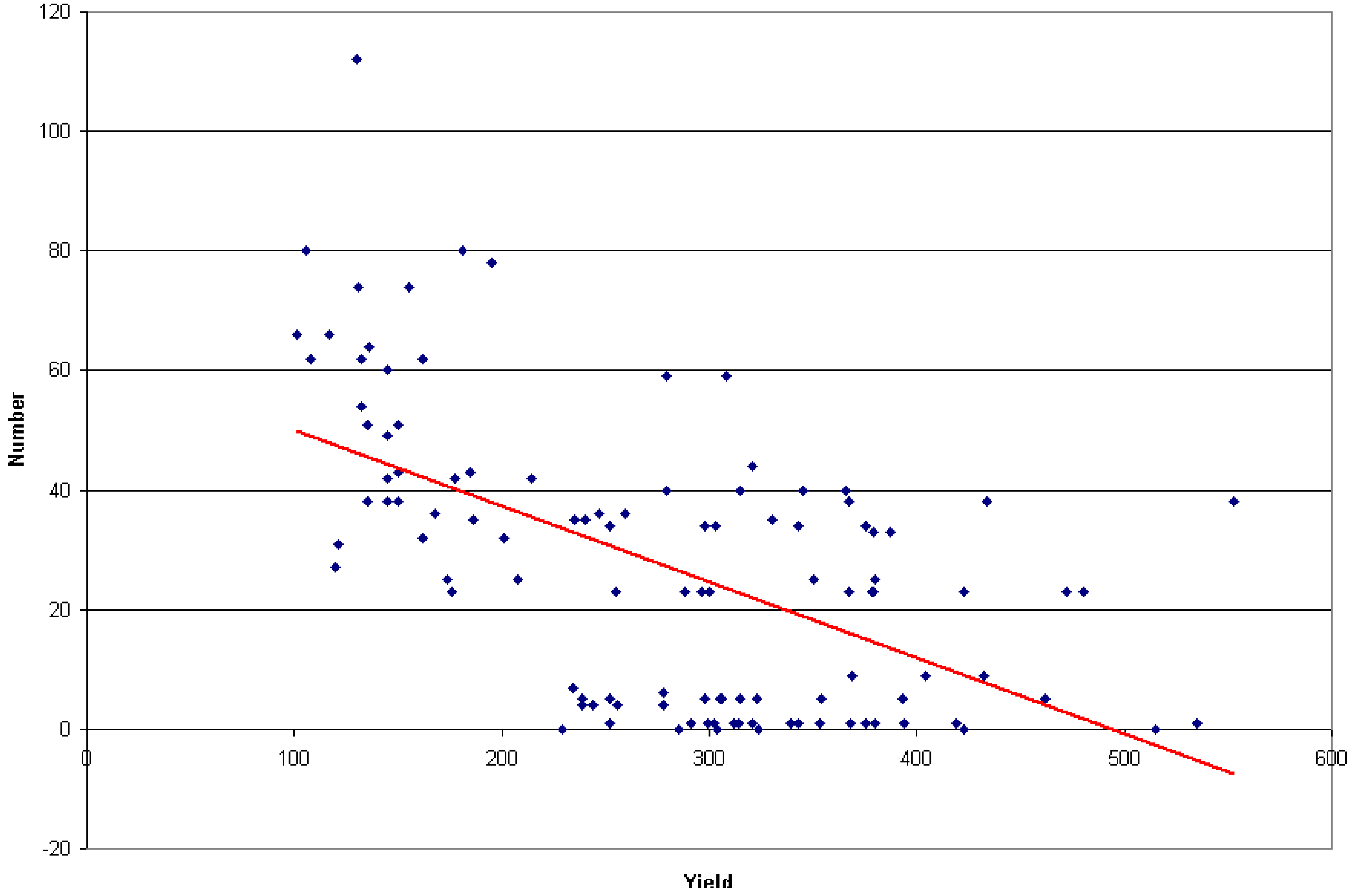


Figure 32: Mature Group 4 Yield versus HT 95s in the Seedform – Fullseed Period

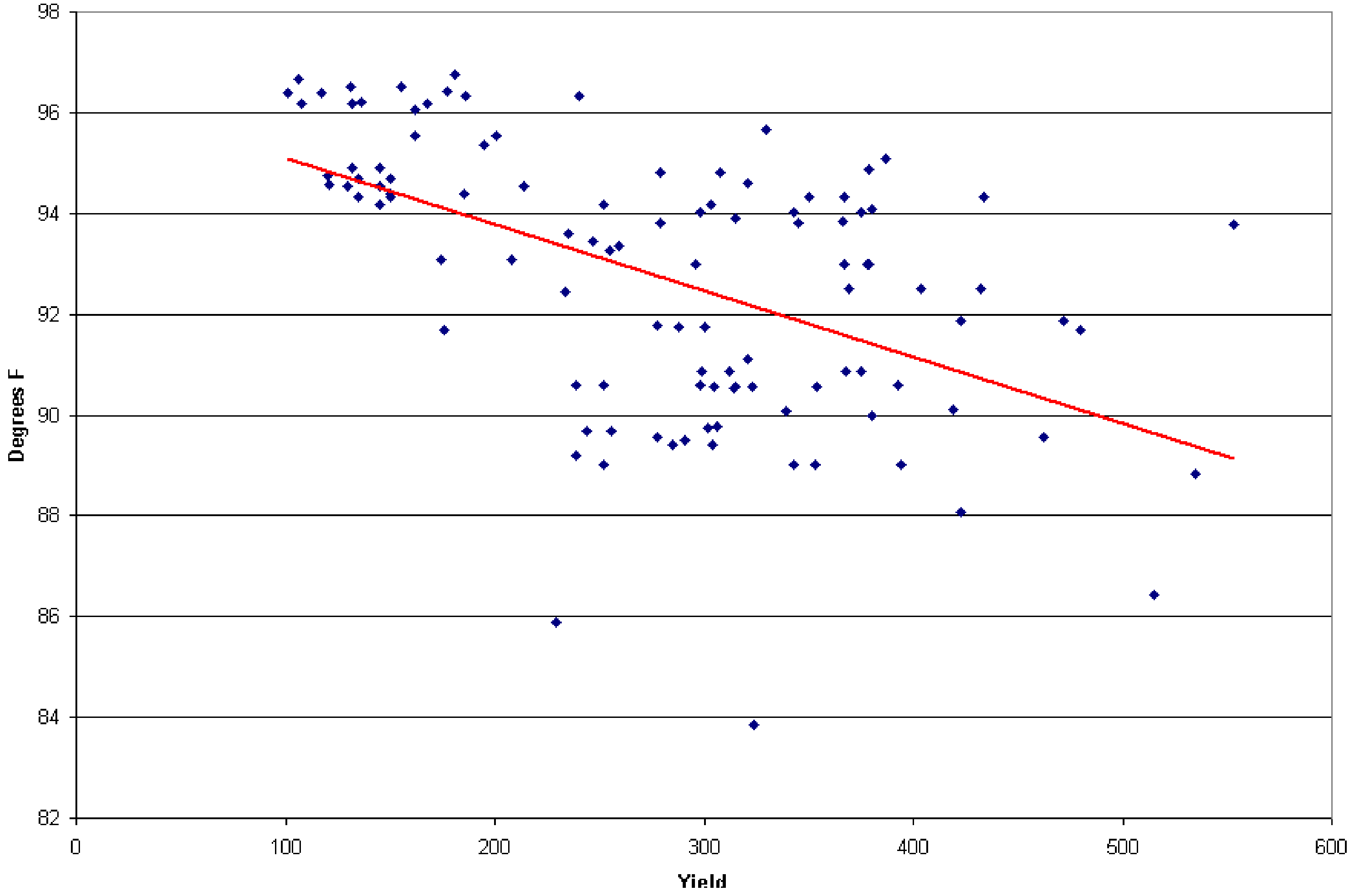


Figure 33: Mature Group 4 Yield versus the Average Maximum Temperature in the Seedform – Fullseed Period

precipitation had correlation coefficients of 0.467, 0.458, and 0.447 respectively, indicating that the wetter it was during the S-F period, the higher the overall yield. Figures 34, 35, and 36 show this relationship between higher amounts of moisture and higher yield.

In the fullseed to mature period of Mature Group 4, the only variables that were important to yield were energy variables. The HT variables were negatively correlated with yield, indicating that higher temperatures dampened yield. HT 95 had a correlation coefficient of –0.391, which was highly significant and showed that the more HT 95s accrued, the lower the resulting yields. Figure 37 shows this relationship between cooler temperatures and higher yield. The absolute maximum temperature was also important in affecting yield, with a correlation coefficient of –0.366, again indicating that higher temperatures resulted in lower yields. Figure 38 shows the relationship between lower absolute maximum temperatures and higher yields.

Table 22 contains the results of the correlation analyses for Mature Group 5. For the total growing season, the energy variables, such as the high HTs and the absolute and average maximum temperatures were the most influential on yield. The absolute maximum temperature had a correlation coefficient of –0.596, which indicates that the higher the absolute maximum temperature, the lower the yield. The correlation coefficient for the average maximum temperature with yield was –0.570, again showing that high temperatures adversely affected yield. For the HT 97 variable, the coefficient was –0.590, which demonstrated that the higher the

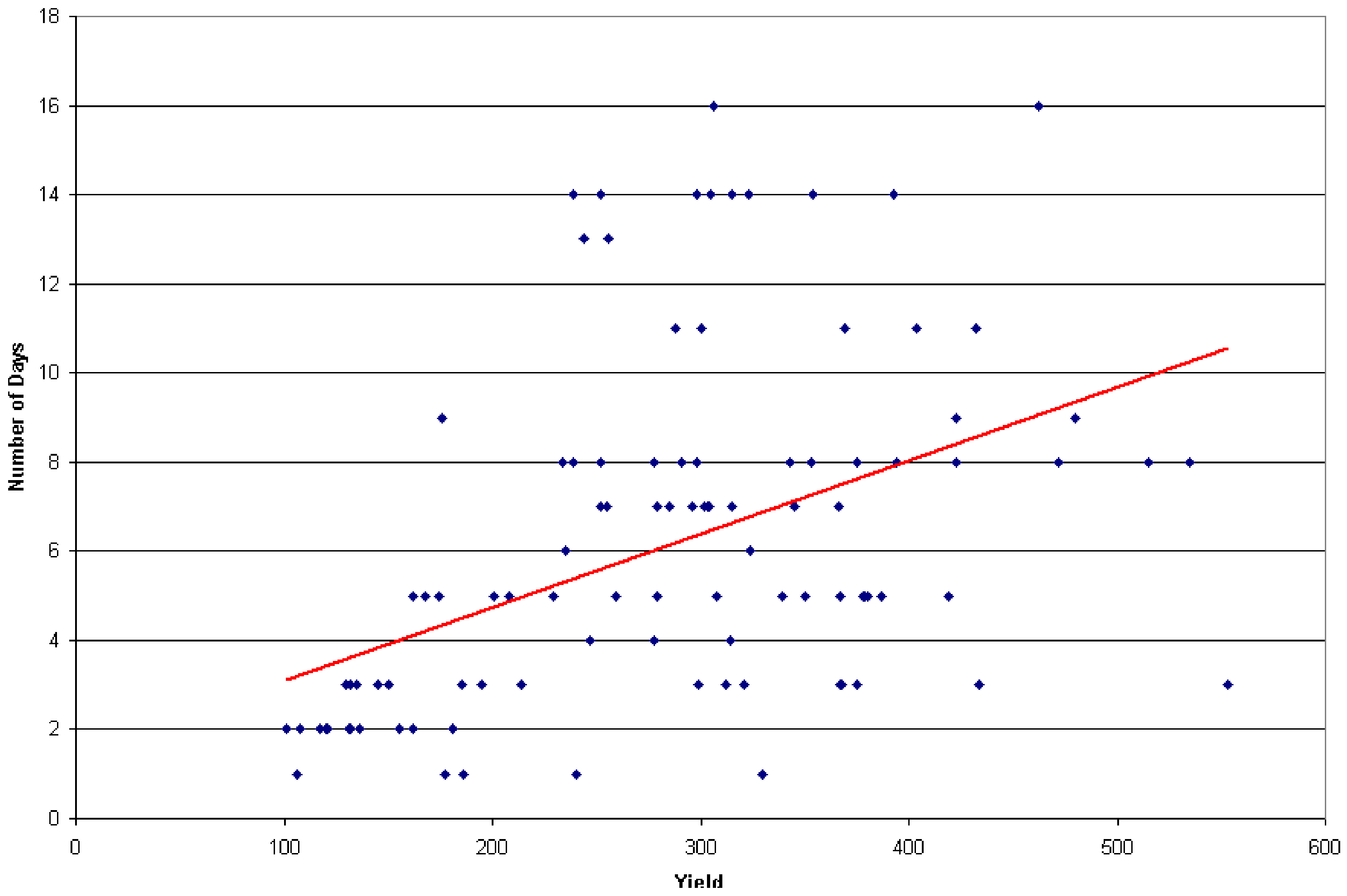


Figure 34: Mature Group 4 Yield versus the Number of Precipitation Days in the Seedform – Fullseed Period

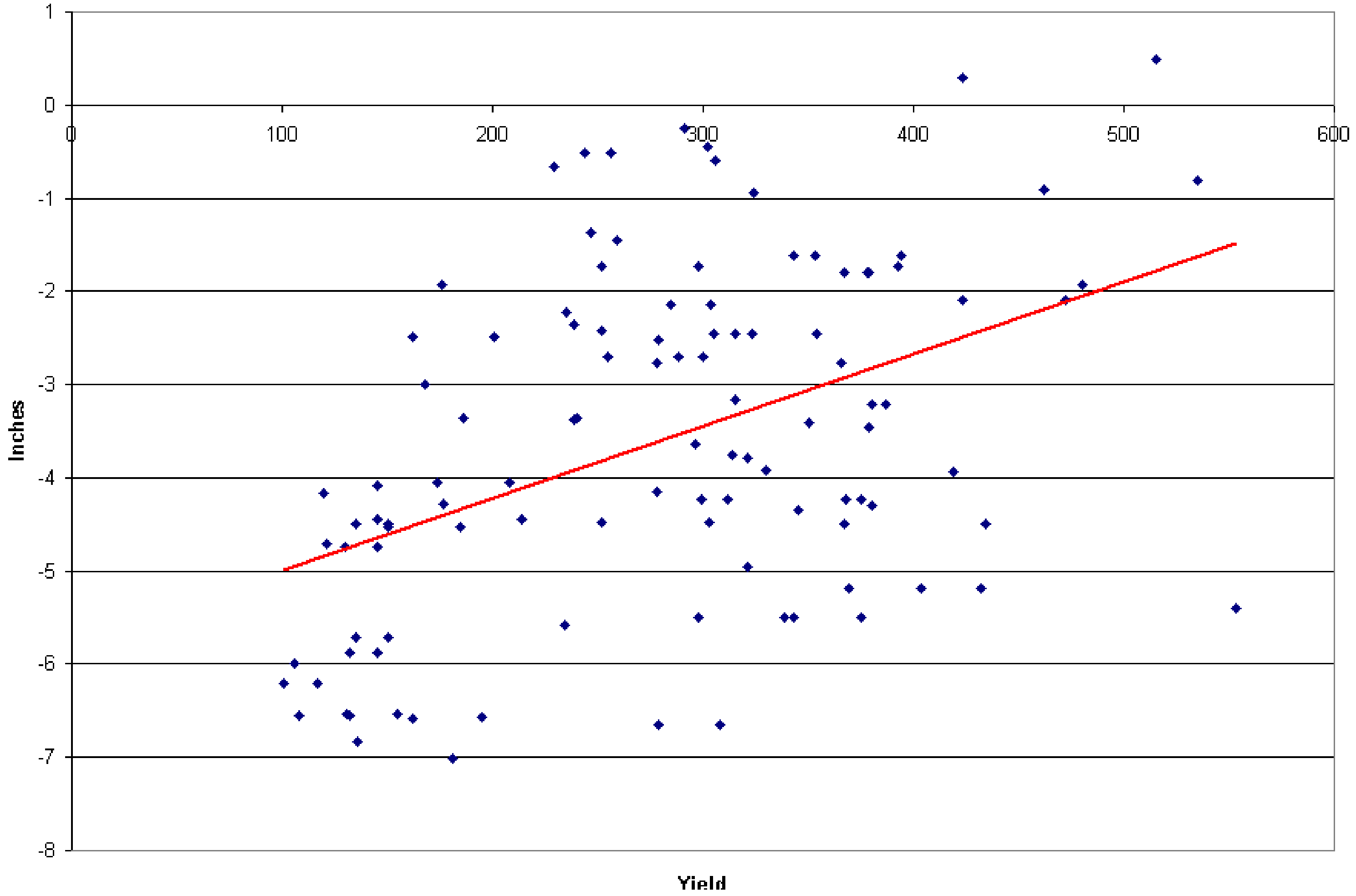


Figure 35: Mature Group 4 Yield versus P – E in the Seedform – Fullseed Period

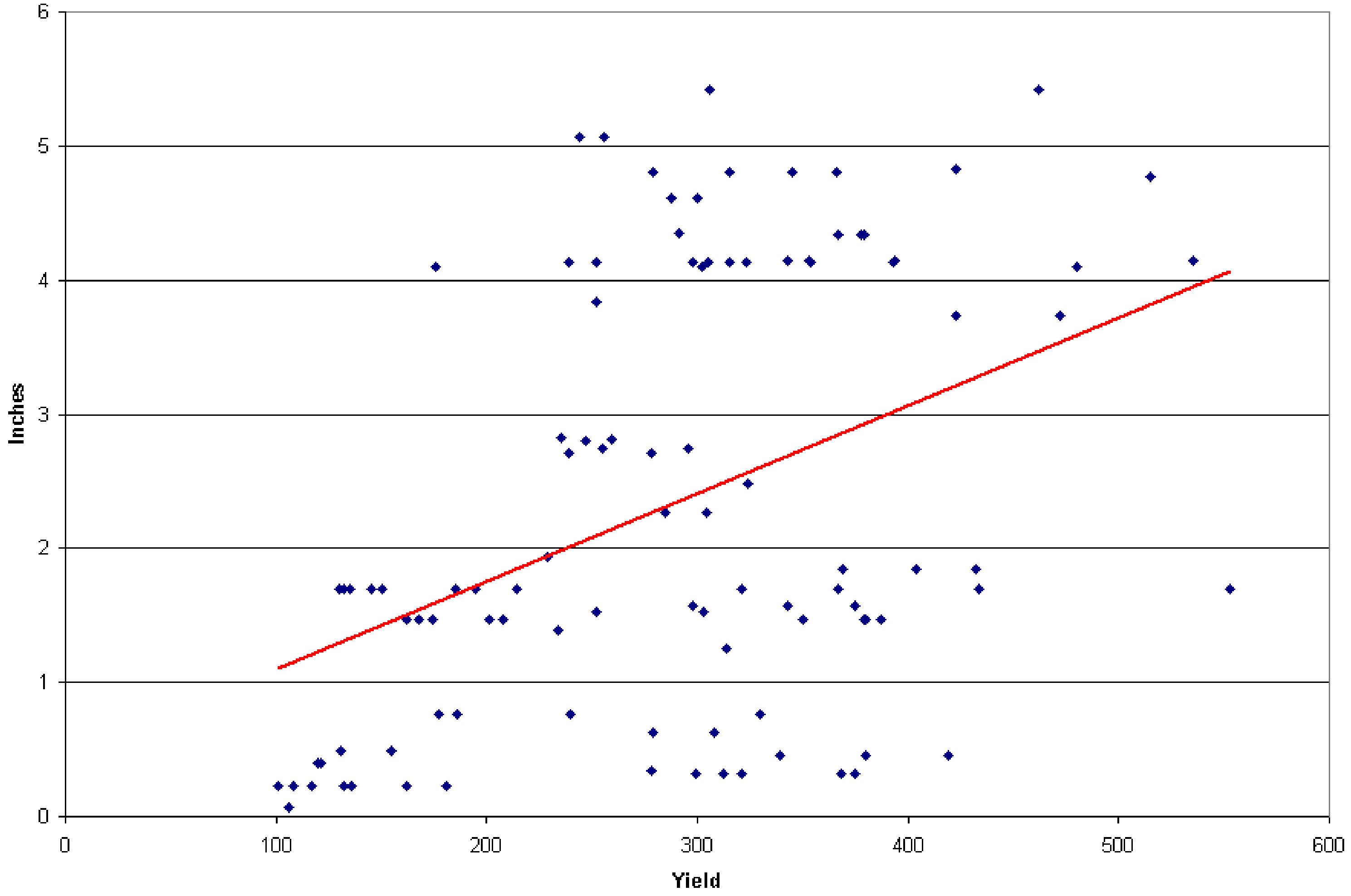


Figure 36: Mature Group 4 Yield versus Precipitation in the Seedform – Fullseed Period

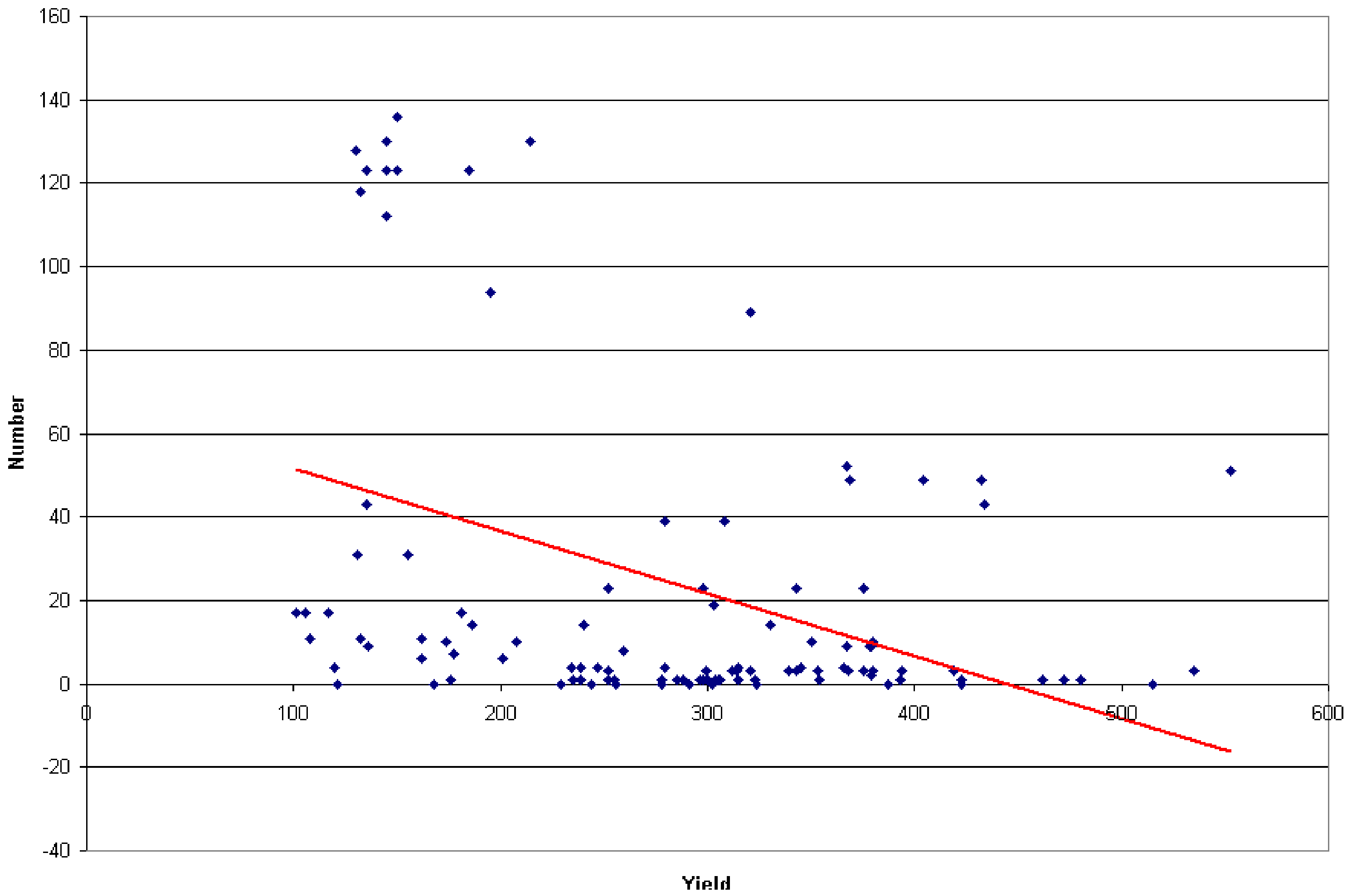


Figure 37: Mature Group 4 Yield versus HT 95s in the Fullseed – Mature Period

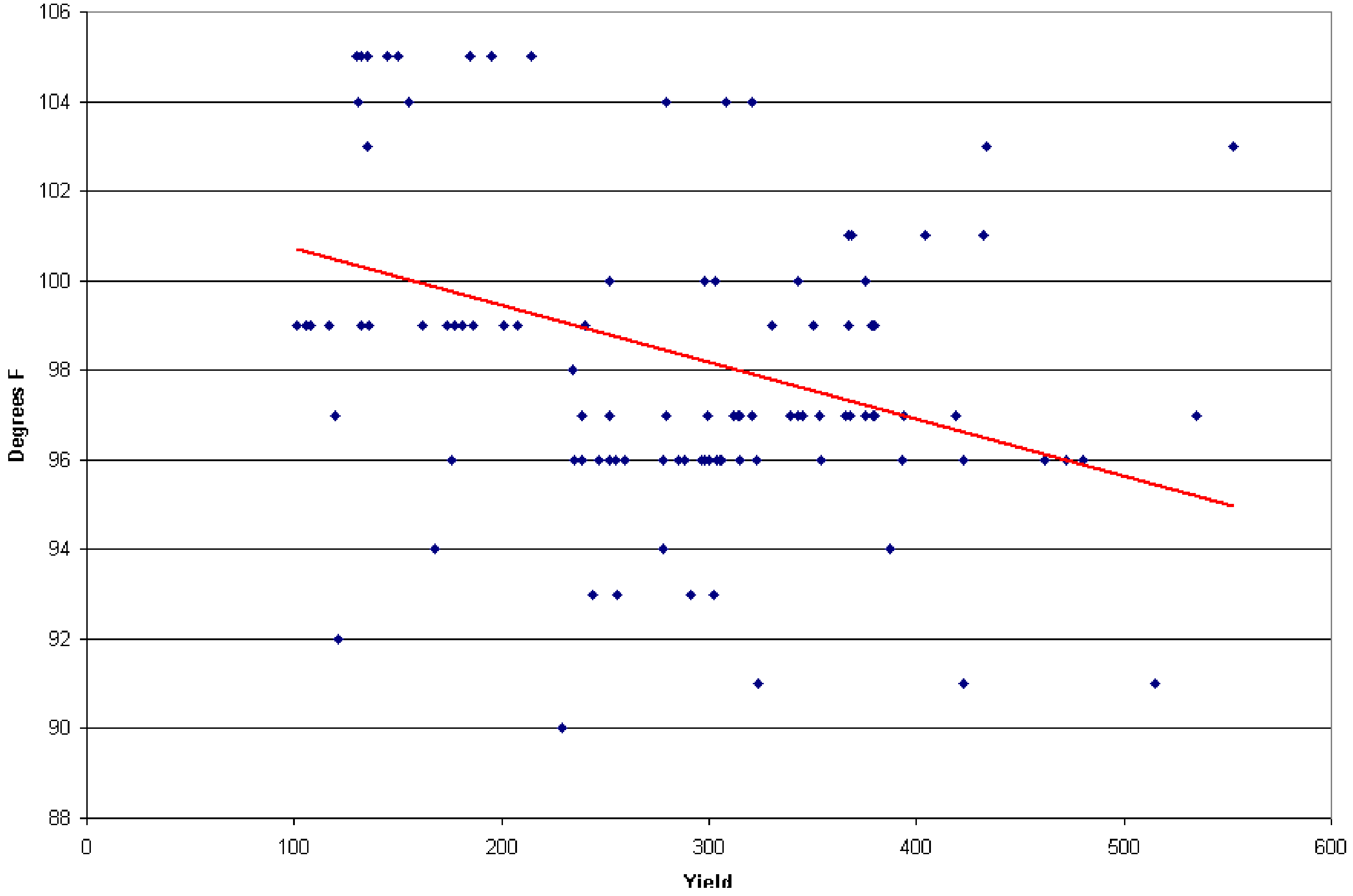


Figure 38: Mature Group 4 Yield versus the Absolute Maximum Temperature in the Fullseed – Mature Period

Table 22: Mature Group 5 Correlation Coefficients and Significance Levels

Total	Correlation factor and Significance
AbsMaxT	-0.596**
HT 97	-0.590**
HT 98	-0.588**
HT 96	-0.587**
AvgMaxT	-0.570**
HT 95	-0.570**
HT 94	-0.555**
HT 93	-0.539**
P Days	0.527**
HT 92	-0.526**
HT 91	-0.515**
HT 90	-0.511**
HT 89	-0.507**
HT 88	-0.497**
P-E	0.493**
HT 87	-0.491**
HT 86	-0.482**
HT 85	-0.470**
Total P	0.457**
+90 Days	-0.444**
AvgMinT	-0.243**
#Days	0.228**
AvgDayLn	0.222*
PlntDate	-0.215*

P-B	Correlation factor and Significance
AbsMinT	-0.438**
AvgDayLn	-0.278**
DD60	-0.246**
AvgMinT	-0.235**
DD50	-0.226**
HT 97	-0.220*
HT 98	-0.204*
+90 Days	-0.188*
P Days	-0.181*
AvgMaxT	-0.180*

B-P	Correlation factor and Significance
AbsMaxT	-0.260**
HT 97	-0.226**
HT 98	-0.222*
AbsMinT	-0.210*
HT 96	-0.207*
HT 95	-0.203*
HT 94	-0.177*
AvgDayLn	-0.171*

P-S	Correlation factor and Significance
HT 93	-0.551**
HT 92	-0.547**
HT 94	-0.542**
HT 90	-0.540**
HT 91	-0.540**
HT 89	-0.536**
HT 95	-0.529**
HT 96	-0.526**
HT 88	-0.523**
HT 97	-0.519**
HT 87	-0.508**
HT 98	-0.497**
HT 86	-0.495**
HT 85	-0.482**
Pdays	0.464**
AvgMaxT	-0.459**
AbsMaxT	-0.446**
+90Days	-0.432**
P-E	0.373**
TotP	0.328**
AvgDayLn	0.254**
AvgMinT	-0.247**
DD60	-0.232**
Plntdate	-0.215*
AbsMinT	-0.214*
DD50	-0.185*

S-F	Correlation factor and Significance
P Days	0.626**
Total P	0.603**
AvgMaxT	-0.595**
AbsMaxT	-0.555**
HT 93	-0.545**
HT 94	-0.541**
HT 95	-0.541**
HT 92	-0.539**
HT 98	-0.535**
HT 96	-0.532**
HT 91	-0.525**
HT 97	-0.523**
HT 90	-0.506**
HT 89	-0.487**
P-E	0.476**
HT 88	-0.468**
HT 87	-0.453**
HT 86	-0.435**
HT 85	-0.414**
+90 Days	-0.345**
AvgDayLn	-0.282**
AvgMinT	-0.187*

F-M	Correlation factor and Significance
AbsMinT	-0.367**
AbsMaxT	-0.352**
HT 91	-0.267**
HT 92	-0.263**
HT 90	-0.258**
AvgMinT	0.257**
P-E	0.253**
Total P	0.248**
HT 93	-0.235**
HT 89	-0.234**
HT 88	-0.219*
P Days	0.218*
HT 94	-0.215*
HT 87	-0.209*
+90 Days	-0.202*
# of Days	0.199*
AvgDayLn	0.196*
HT 95	-0.194*
HT 86	-0.192*
AvgMaxT	-0.187*
HT 85	-0.174*

** Highly Significant at the 0.01 Level
* Significant at the 0.05 Level

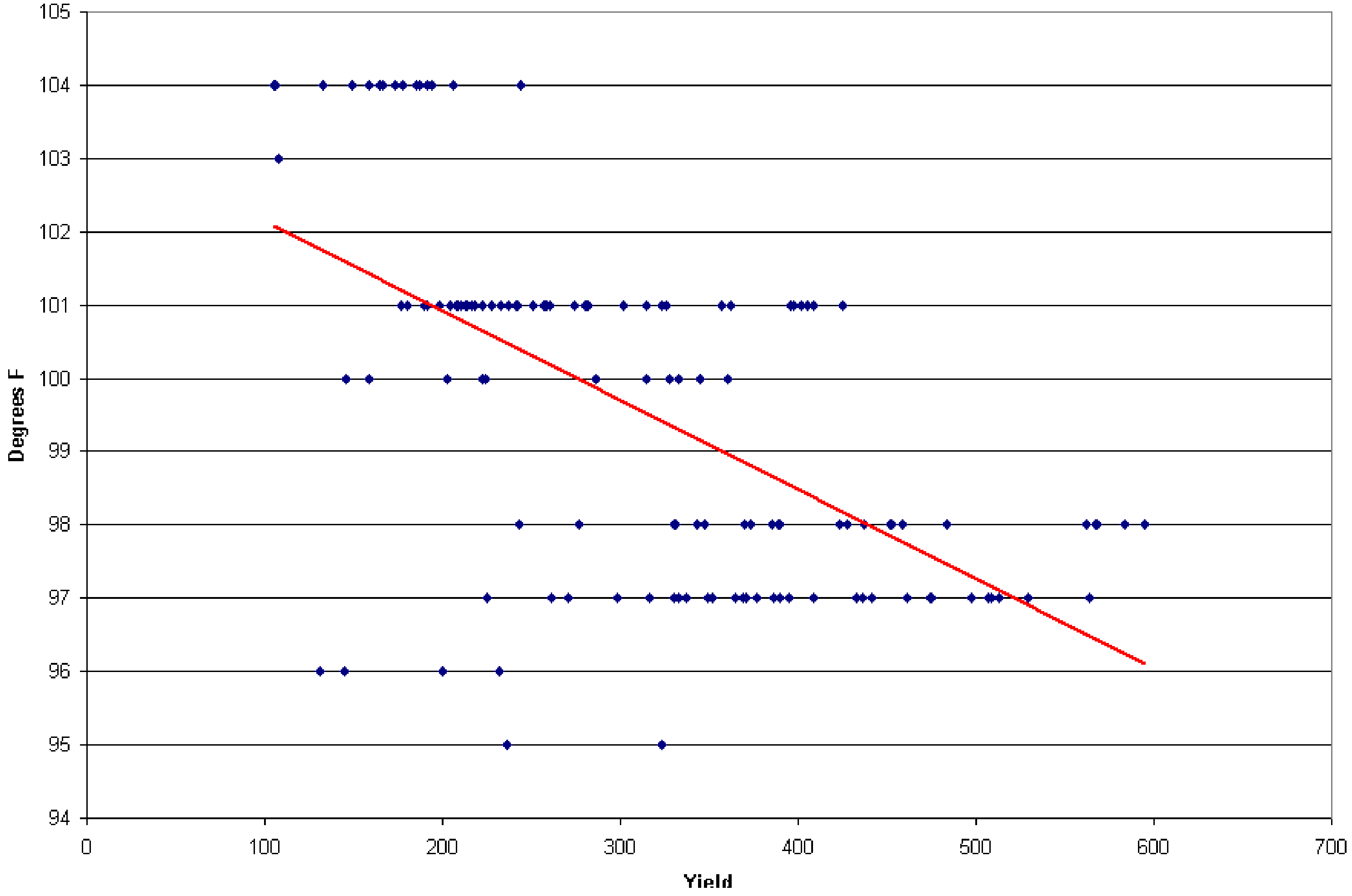


Figure 39: Mature Group 5 Yield versus the Absolute Maximum Temperature for the Entire Growing Period

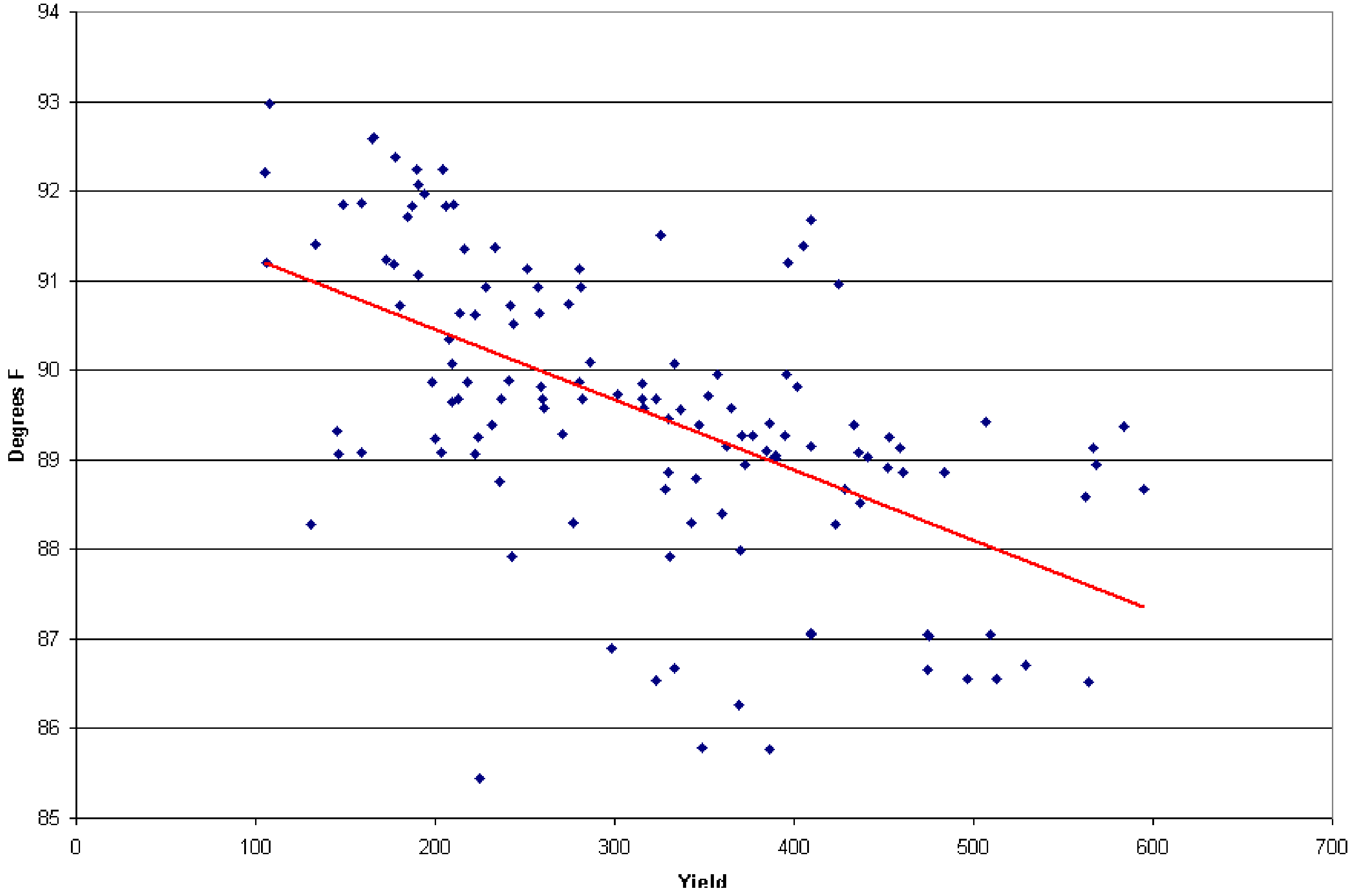


Figure 40: Mature Group 5 Yield versus the Average Maximum Temperature for the Entire Growing Period

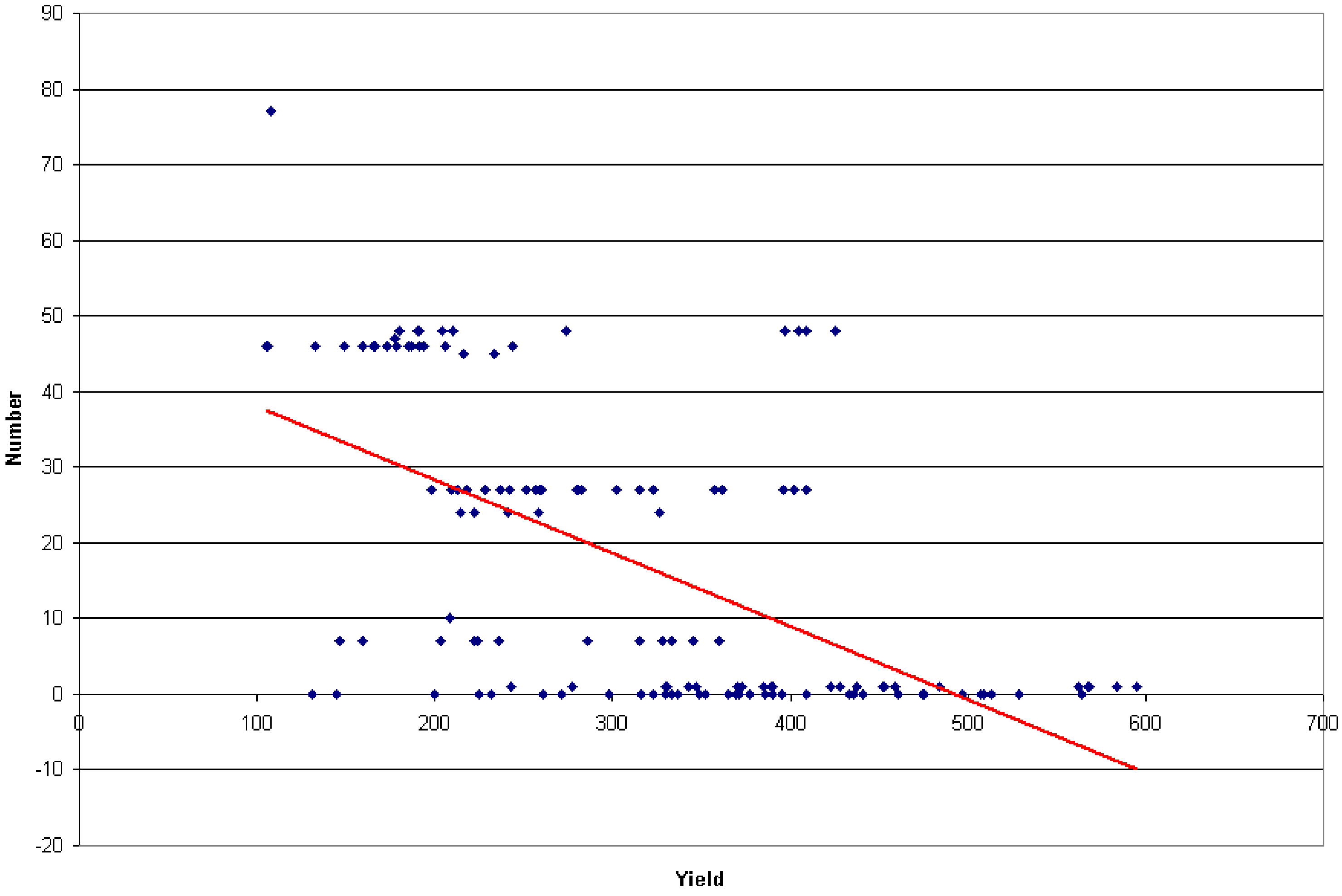


Figure 41: Mature Group 5 Yield versus HT 97s for the Entire Growing Period

number of accrued HT 97s, the lower the yield. Figures 39, 40, and 41 are scatter plots that show the relationships between higher yields and lower high temperatures. The moisture variables, the number of precipitation days, P-E, and total precipitation were also highly significant to yield. The correlation coefficients for these variables were 0.527, 0.493, and 0.457, respectively, which indicates that the wetter it was overall during the entire growing season, the better the yield. Figures 42, 43 and 44 graphically show this relationship.

For the plant to bloom period for Mature Group 5, the absolute minimum temperature variable was most strongly correlated with yield, with a correlation coefficient of –0.438, which was highly significant and indicated that the cooler it was during the P-B period the higher the yield. Figure 45 shows this relationship between cooler temperatures and higher yield. Average minimum temperature was also negatively correlated with yield, with a coefficient of –0.235 that was highly significant and also confirmed that cooler temperatures were associated with higher yields. Figure 46 shows the relationship between average minimum temperature and yield.

In the bloom to podset period for Mature Group, energy variables most influenced yield. Absolute maximum temperatures had a correlation coefficient of –0.260, indicating that higher temperatures during the B-P period corresponded with a decrease in yield. Figure 47 shows this trend. HT 97 was also highly significant, with a correlation coefficient of –0.226, which again indicates that higher

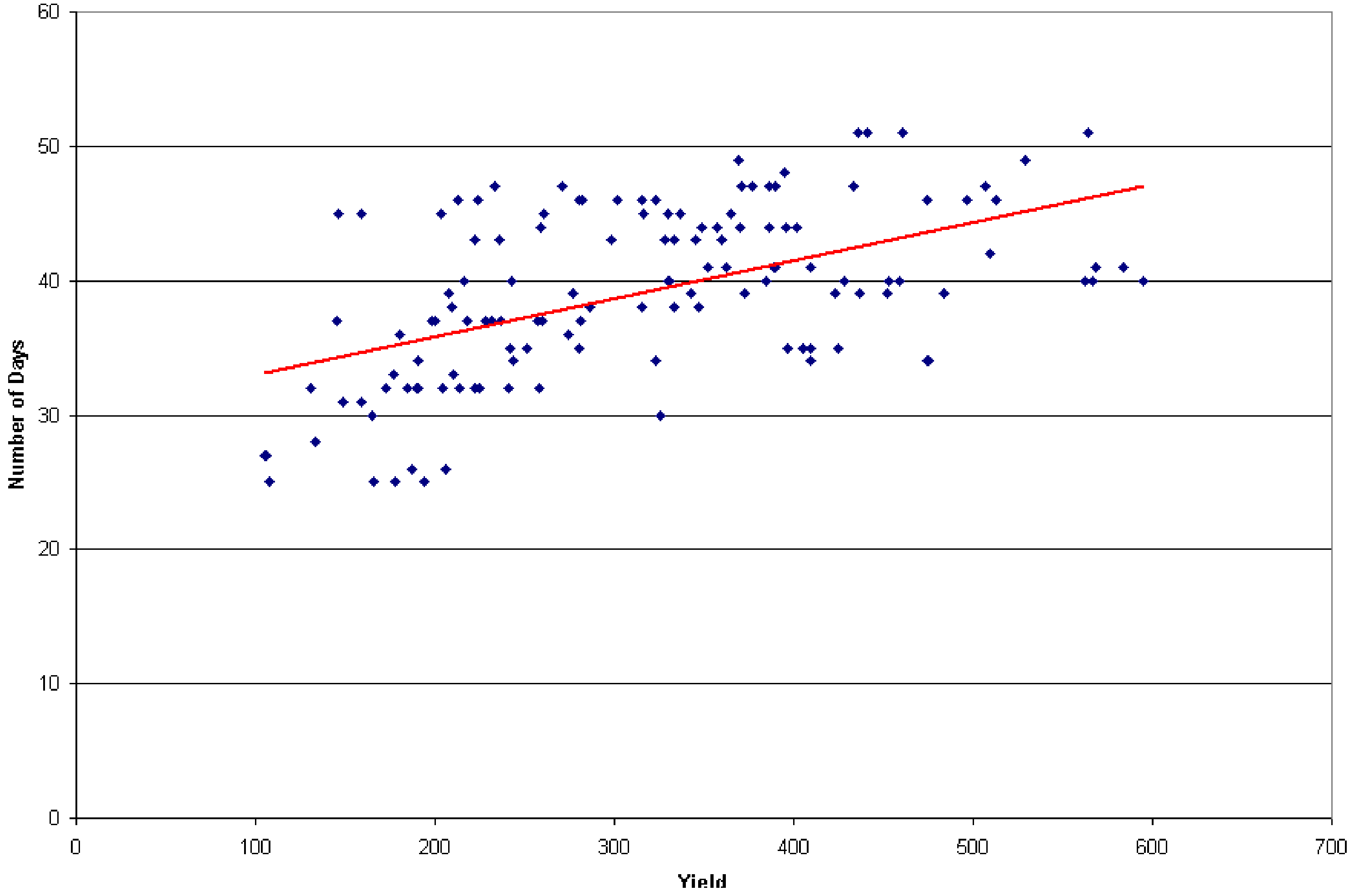


Figure 42: Mature Group 5 Yield versus the Number of Precipitation Days for the Entire Growing Period

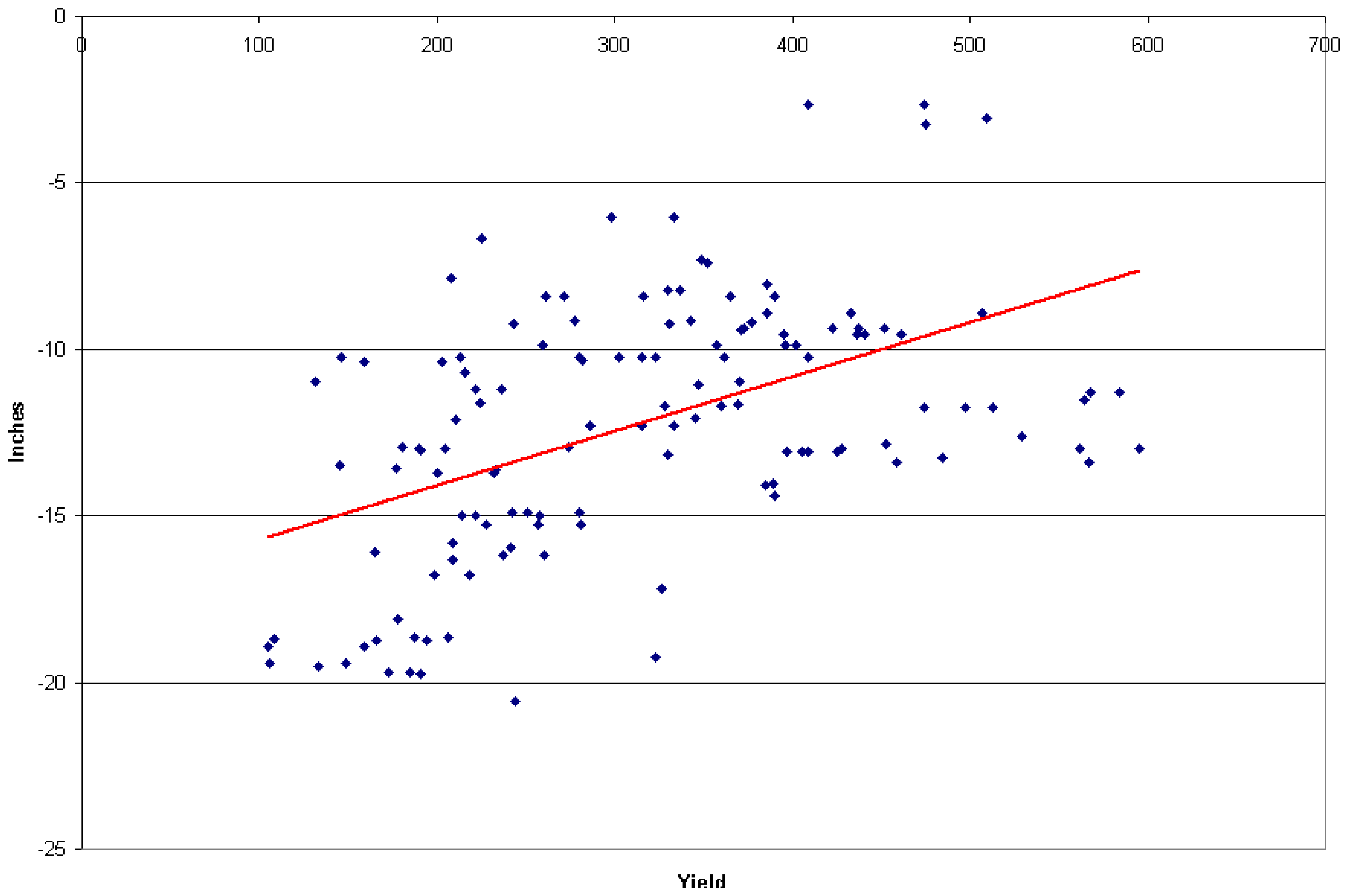


Figure 43: Mature Group 5 Yield versus P – E for the Entire Growing Period

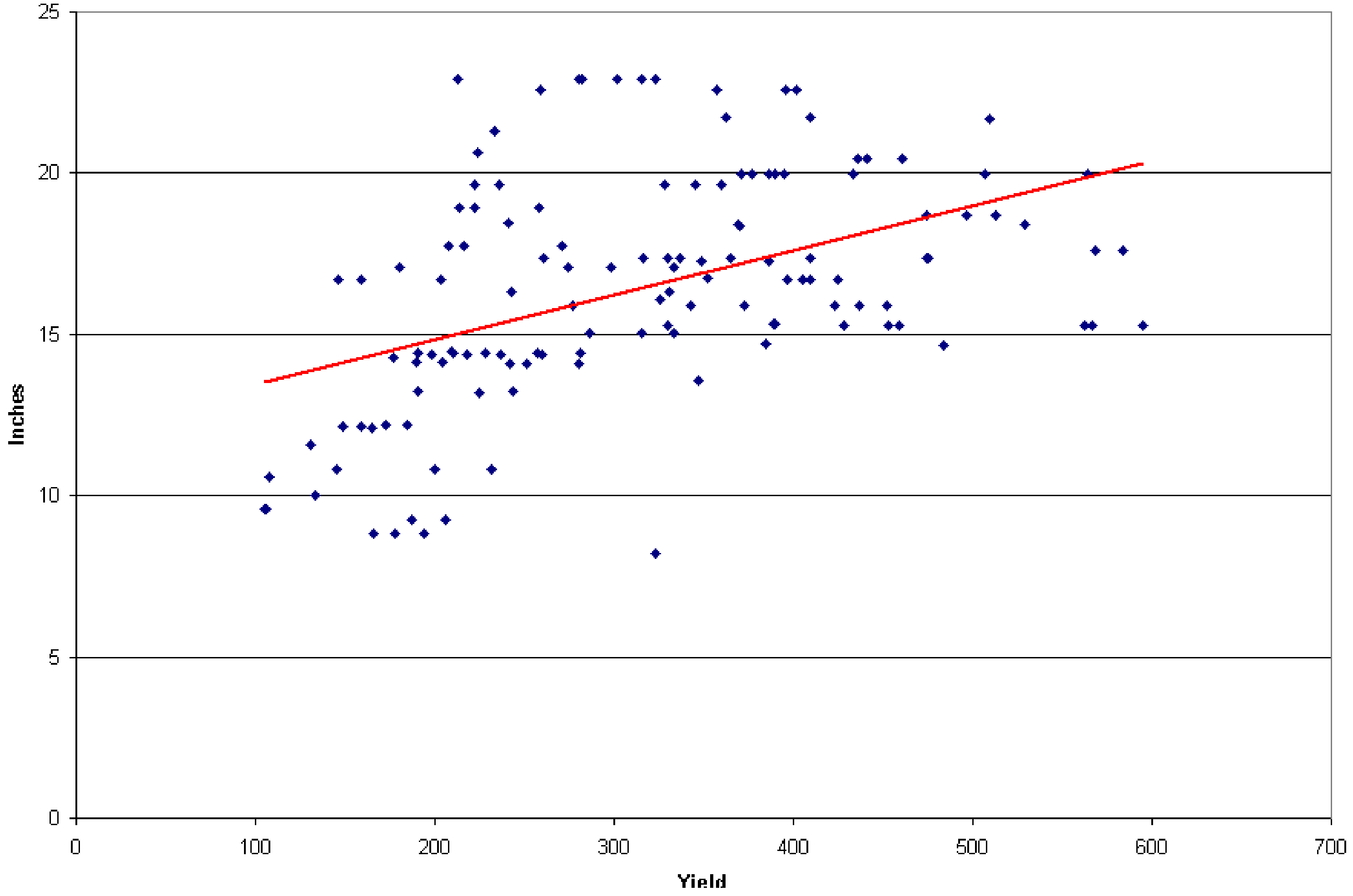


Figure 44: Mature Group 5 Yield versus Precipitation for the Entire Growing Period

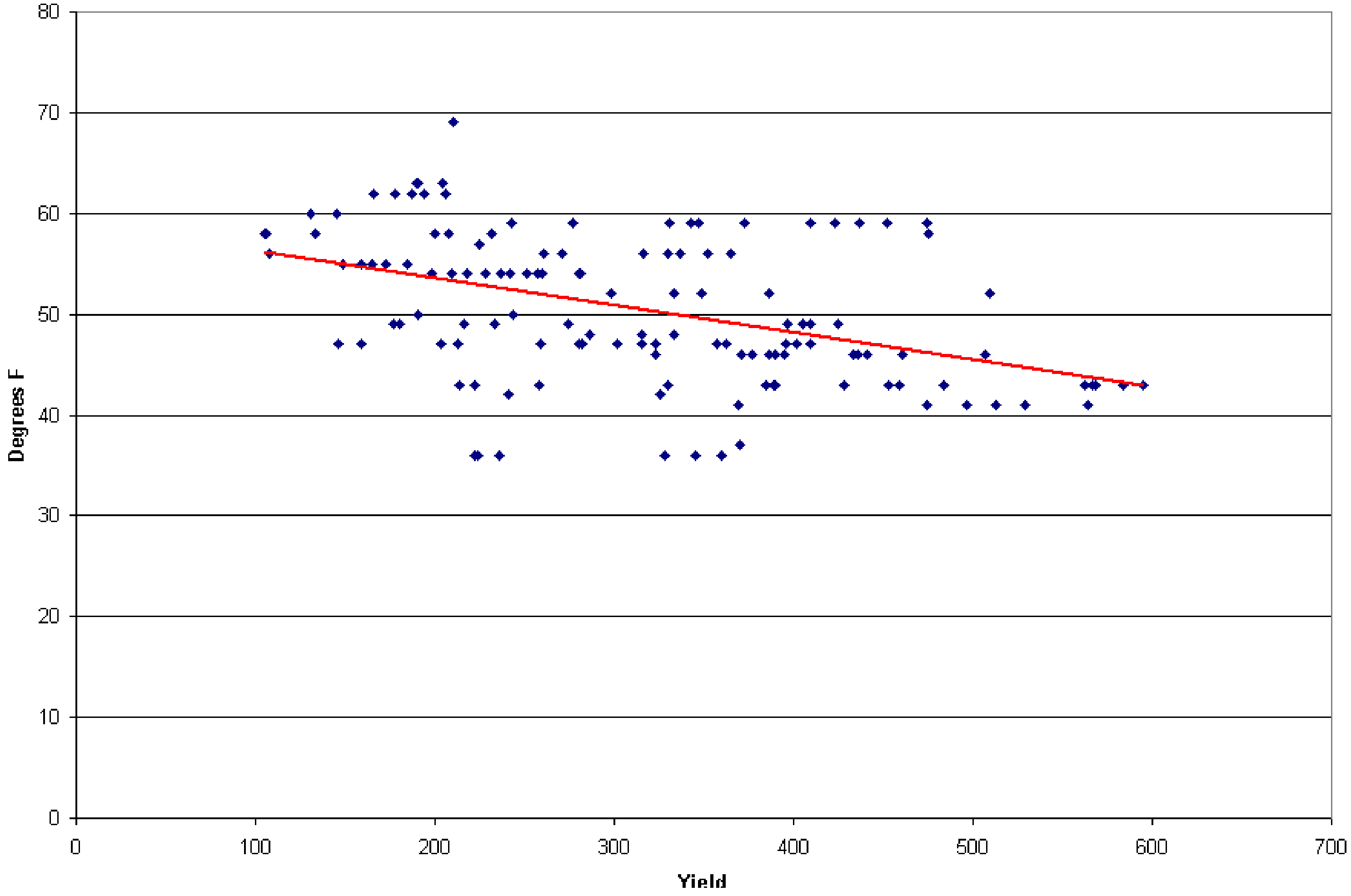


Figure 45: Mature Group 5 Yield versus the Absolute Minimum Temperature for the Plant – Bloom Period

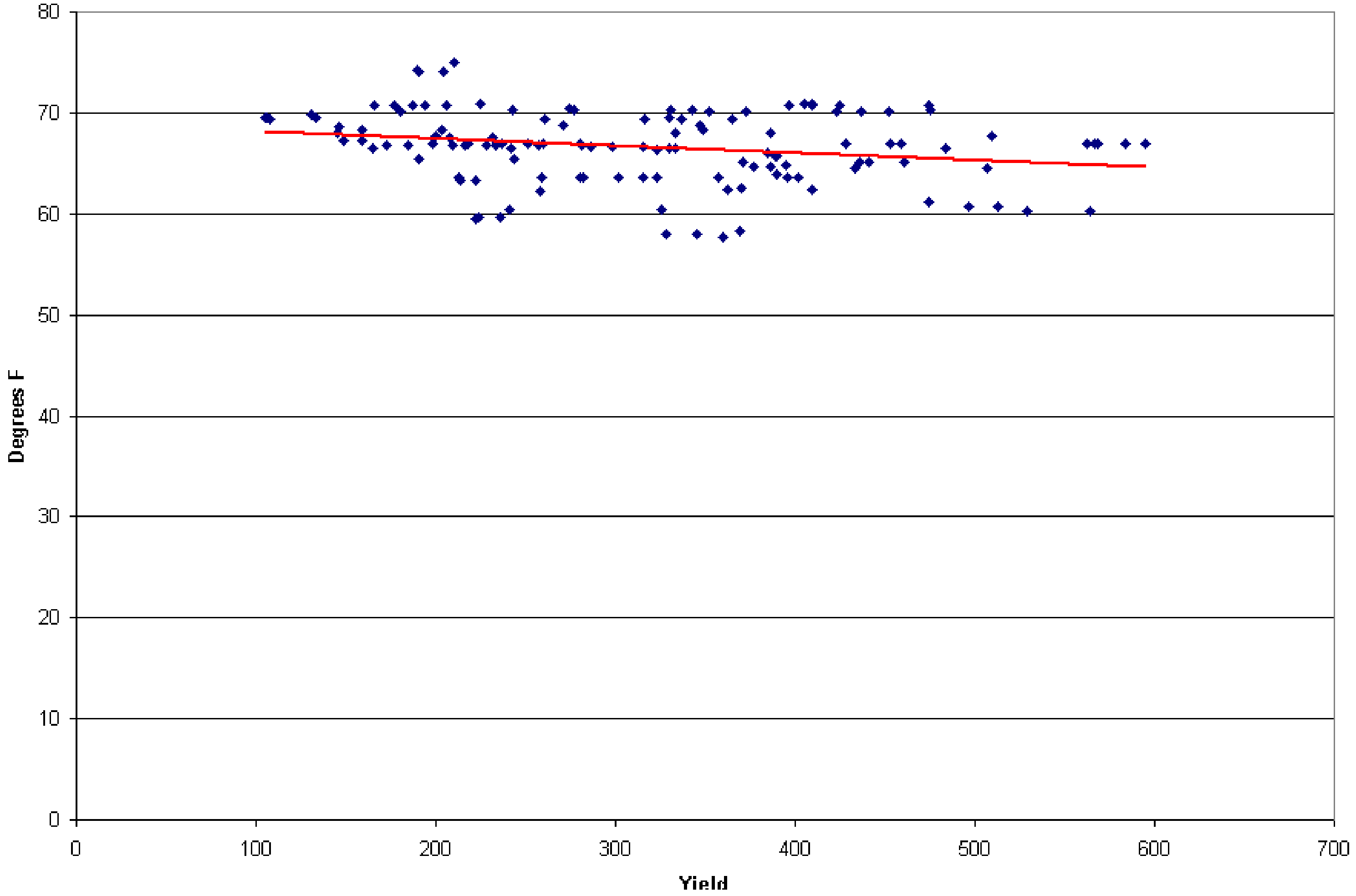


Figure 46: Mature Group 5 Yield versus the Average Minimum Temperature for the Plant – Bloom Period

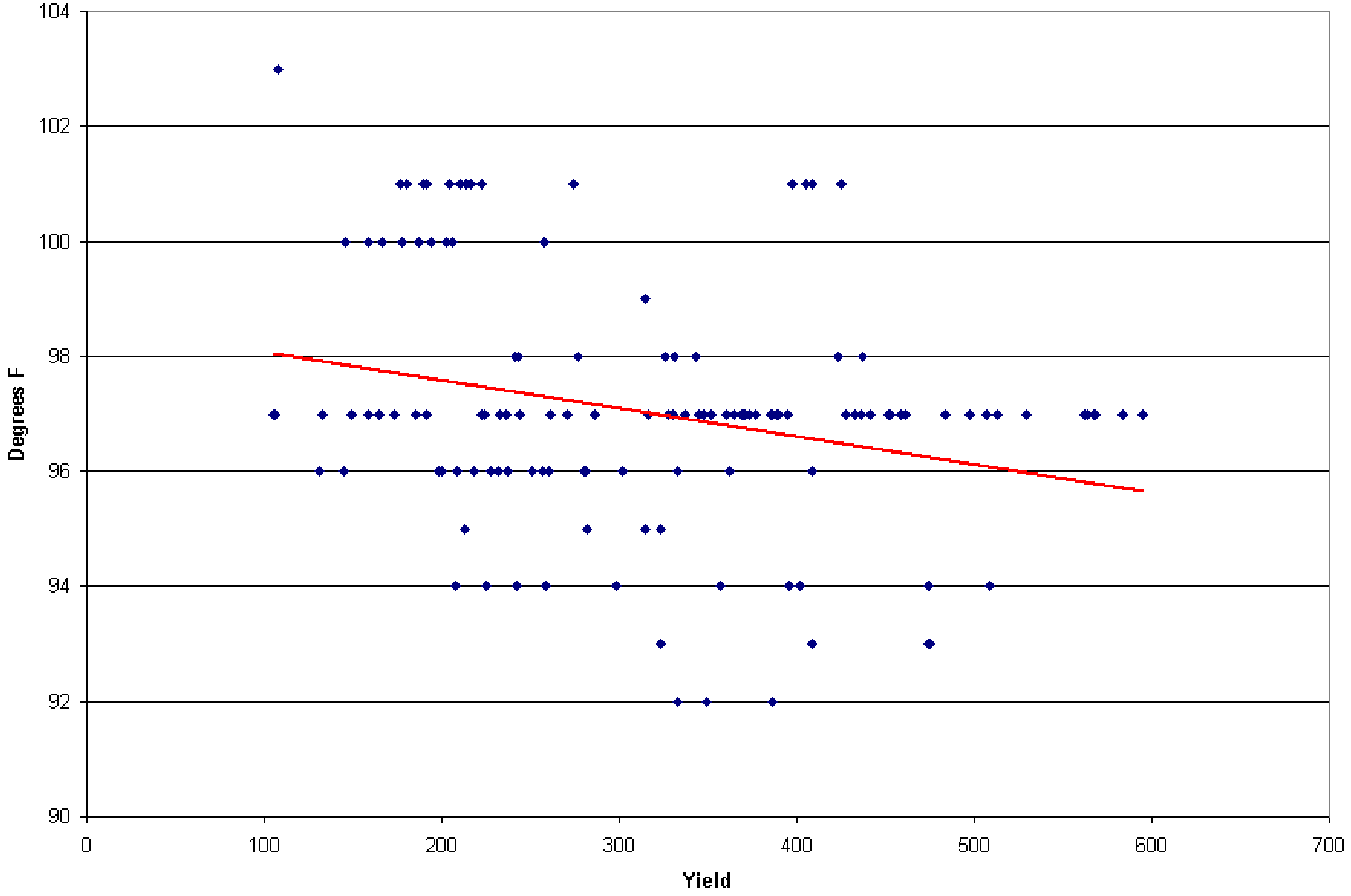


Figure 47: Mature Group 5 Yield versus the Absolute Maximum Temperature for the Bloom –Podset Period

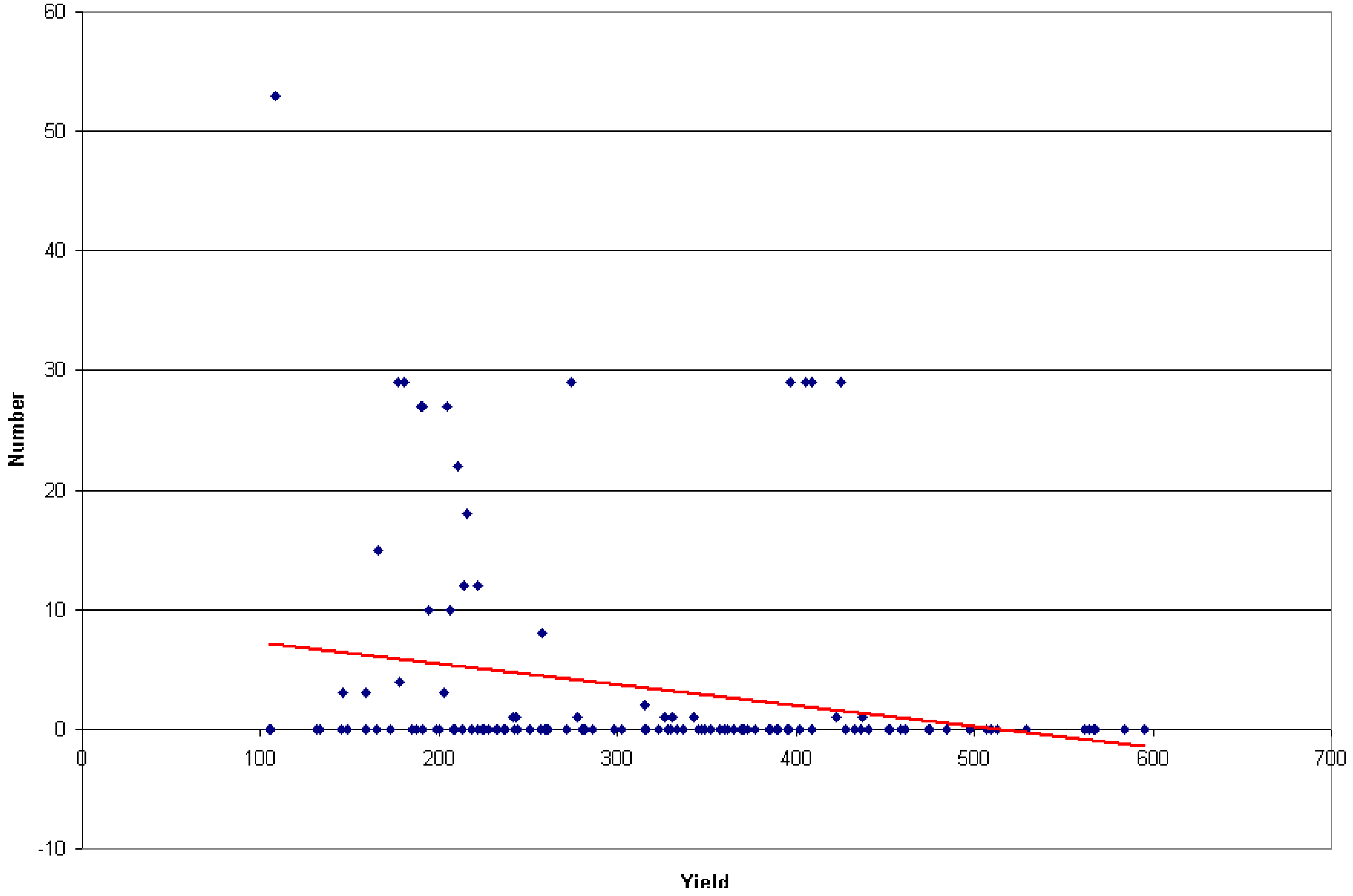


Figure 48: Mature Group 5 Yield versus HT 97s for the Bloom – Podset Period

temperatures in the B-P period tended to depress yield. Figure 48 shows the relationship of higher temperatures in the B-P period with yield.

In the podset to seedform period for Mature Group 5, the high temperatures variables correlated most strongly with yield. For example, HT 93 and HT 97 had highly significant correlation coefficients of –0.551 and –0.519, respectively, which indicates that higher temperatures during the S-F period were associated with a decrease in yield. Figures 49 and 50 show the relationship between lower temperatures in the S-F period and higher yields. Water was also important to yield in the S-F period. The correlation coefficient for the number of precipitation days was 0.464, and the coefficient for total precipitation was 0.328, both of which were highly significant and indicate that those soybeans that received more rain were higher yielding. Figures 51 and 52 demonstrate this relationship between higher amounts of rainfall and increased yield.

In the seedform to fullseed period for Mature Group 5, the number of precipitation days and total precipitation strongly correlated with yield. The correlation coefficient for the number of precipitation days was 0.626, and the coefficient for total precipitation was 0.603, both of which were highly significant and indicates that the wetter it was during the S-F period, the higher the overall yield. Precipitation – evaporation was important to yield as well; its correlation coefficient was 0.476, which again indicates that those soybean that were under less evaporative stress produced higher yields. Figures 53, 54, and 55 show the relationship between wetter conditions in the S-F period and higher overall yield.

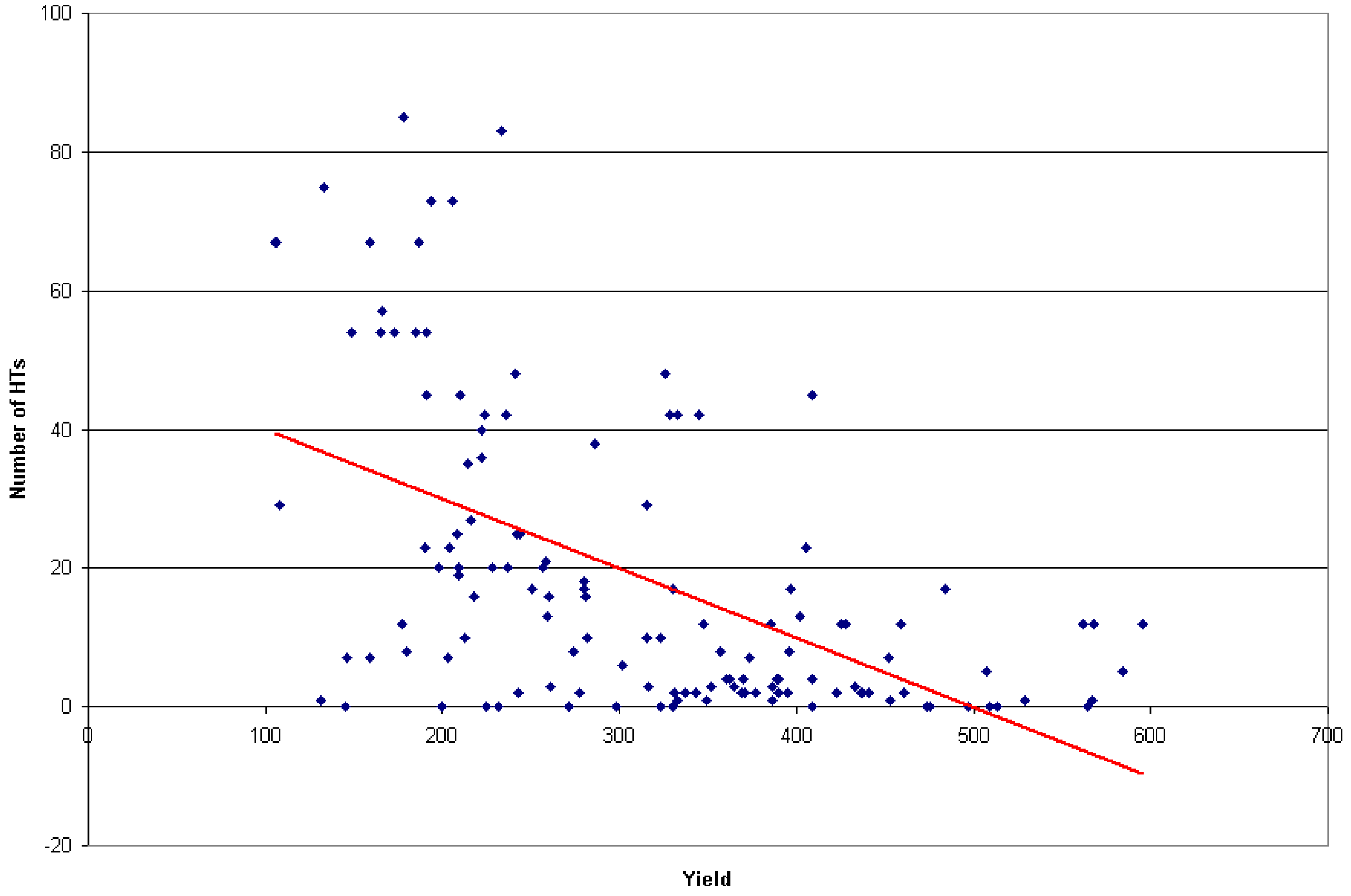


Figure 49: Mature Group 5 Yield versus HT 93s in the Podset – Seedform Period

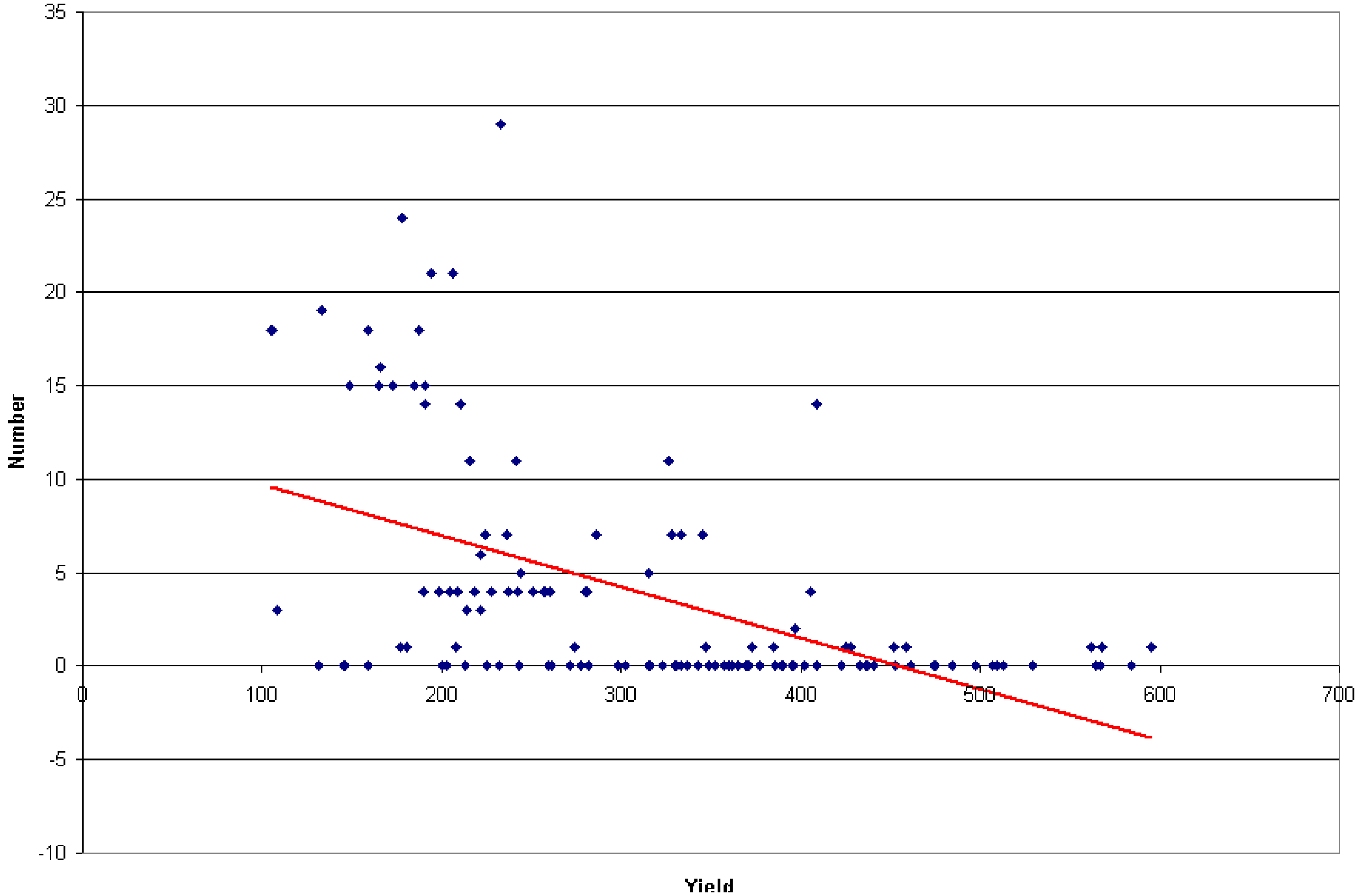


Figure 50: Mature Group 5 Yield versus HT 97s in the Podset – Seedform period

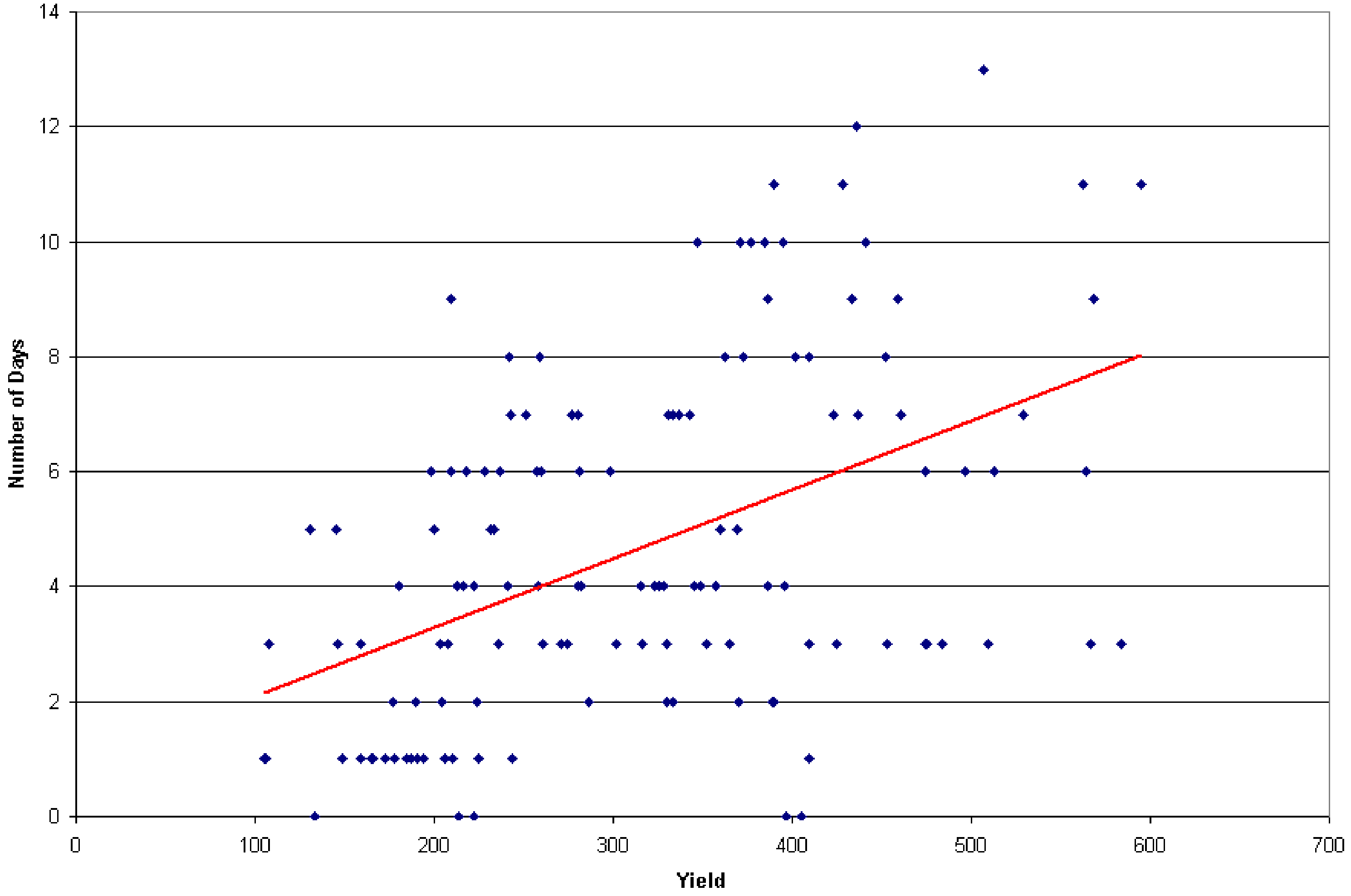


Figure 51: Mature Group 5 Yield versus the Number of Precipitation Days in the Podset – Seedform Period

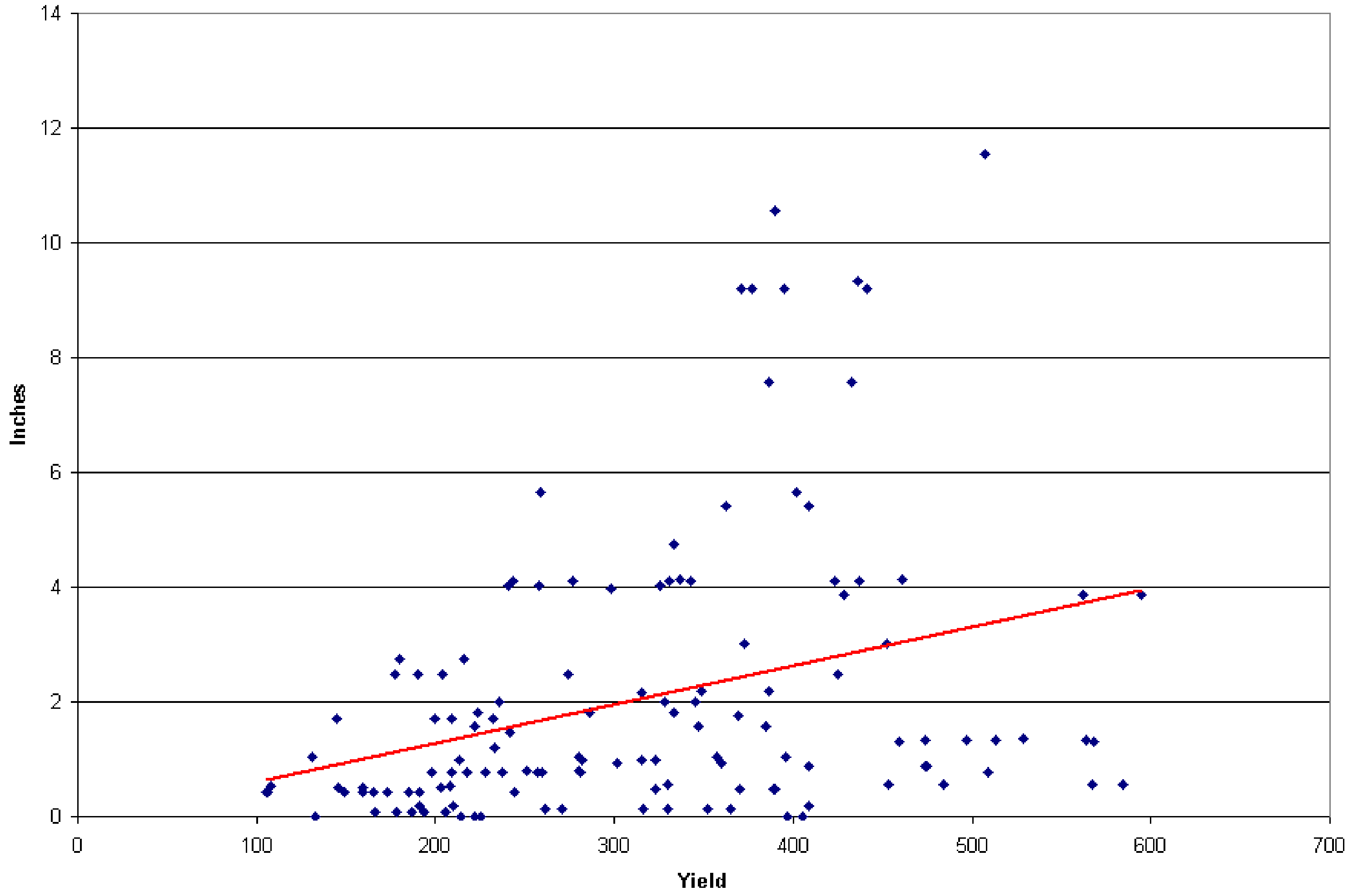


Figure 52: Mature Group 5 Yield versus Precipitation in the Podset – Seedform Period

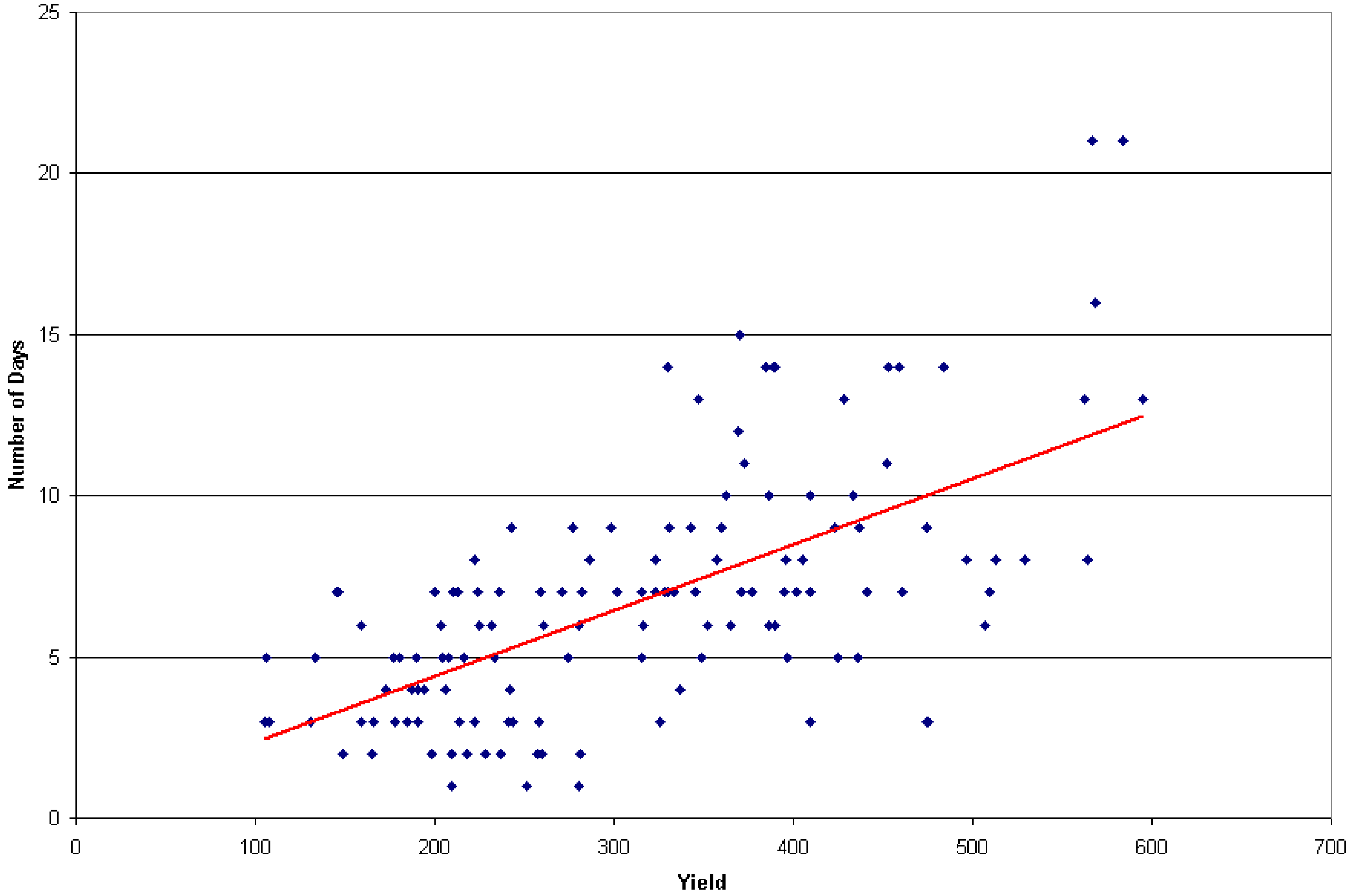


Figure 53: Mature Group 5 Yield versus the Number of Precipitation Days in the Seedform – Fullseed Period

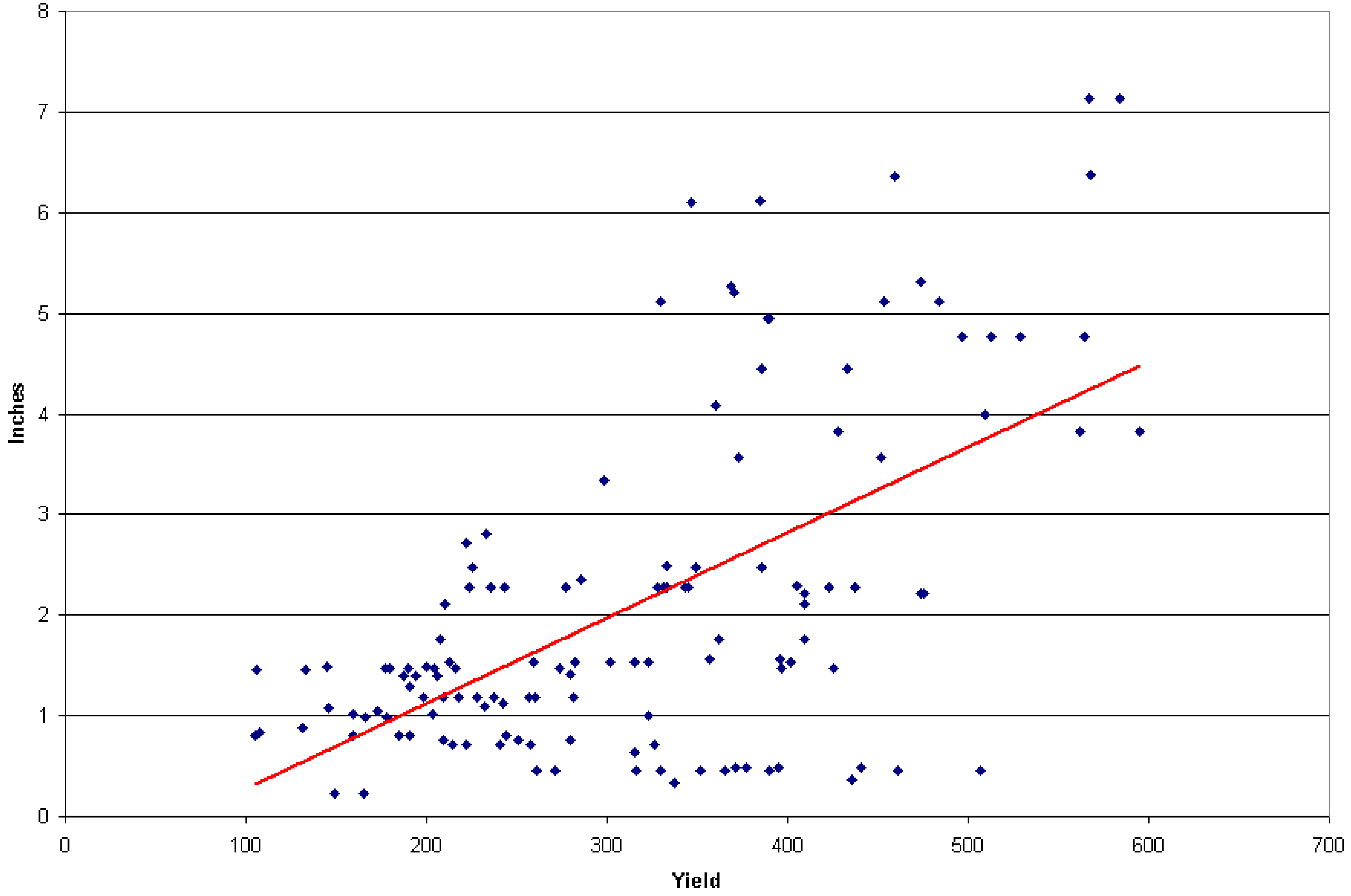


Figure 54: Mature Group 5 Yield versus Precipitation in the Seedform – Fullseed Period

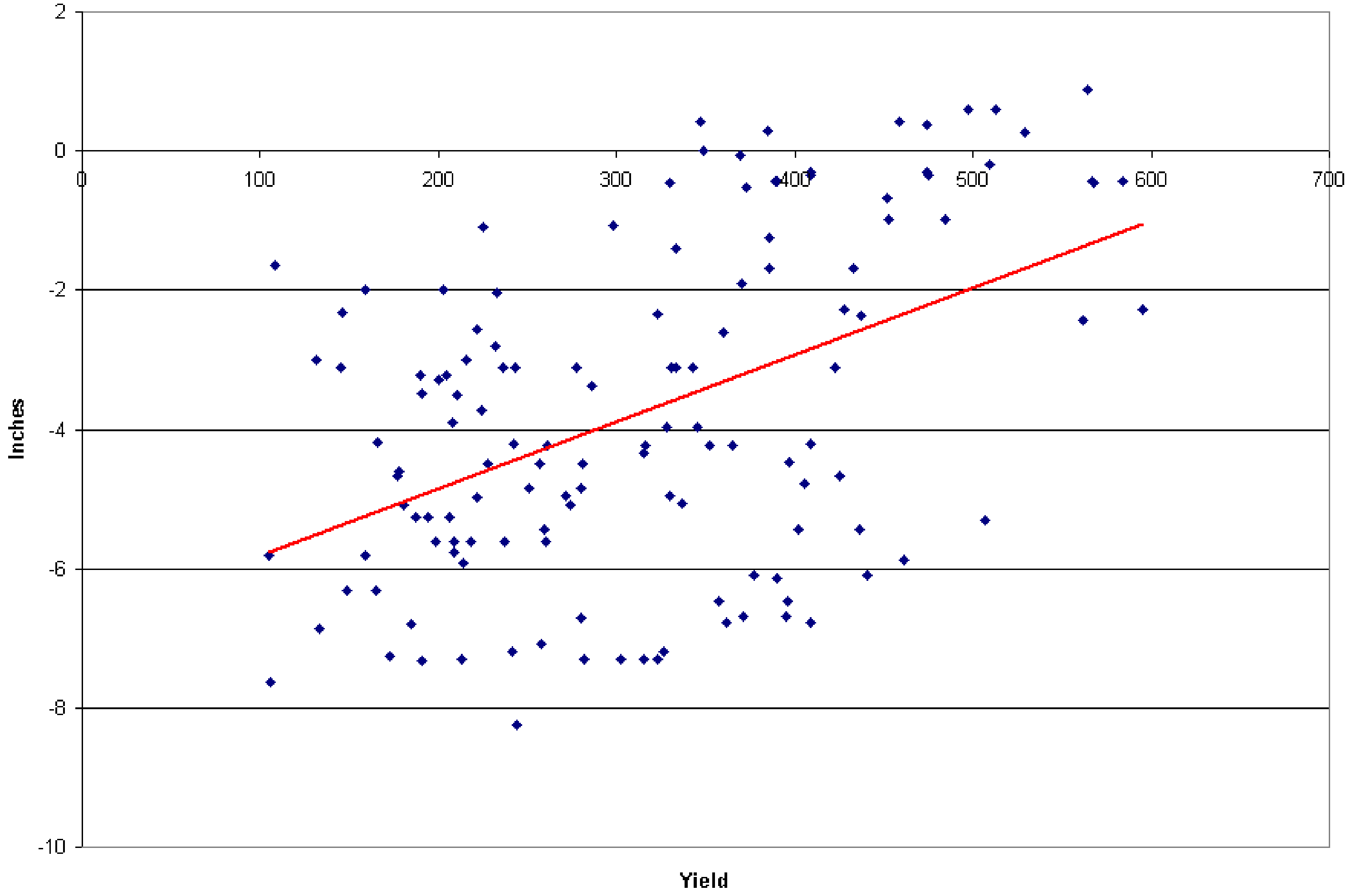


Figure 55: Mature Group 5 Yield versus P – E in the Seedform – Fullseed Period

High temperatures during the S-F period also had an effect on yield, although a negative one. The average maximum temperature had a correlation coefficient of -0.595, which was highly significant and showed that higher temperatures during the S-F period were associated with lower yields. HT 98 had a correlation coefficient of –0.535, again showing that high temperatures during the S-F period adversely affected yield. Figures 56 and 57 show the relationship between higher temperatures in the S-F period and lower yields.

In the fullseed to mature period for Mature Group 5, cooler temperatures and wetter conditions during the F-M were again associated with higher yields. For example, the correlation coefficients for the absolute minimum temperature and absolute maximum temperatures were –0.367 and –0.352, which were both highly significant and show that the cooler it was during the F-M period the higher the yield. Figures 58 and 59 graphically show the relationship between temperature and yield. Total precipitation during the F-M period and precipitation – evaporation were also highly significant, with correlation coefficients of 0.253 and 0.248, respectively. Figures 60 and 61 demonstrate that the wetter it was during the F-M period (the less evaporative stress the plants were subjected to), the higher the resultant yield.

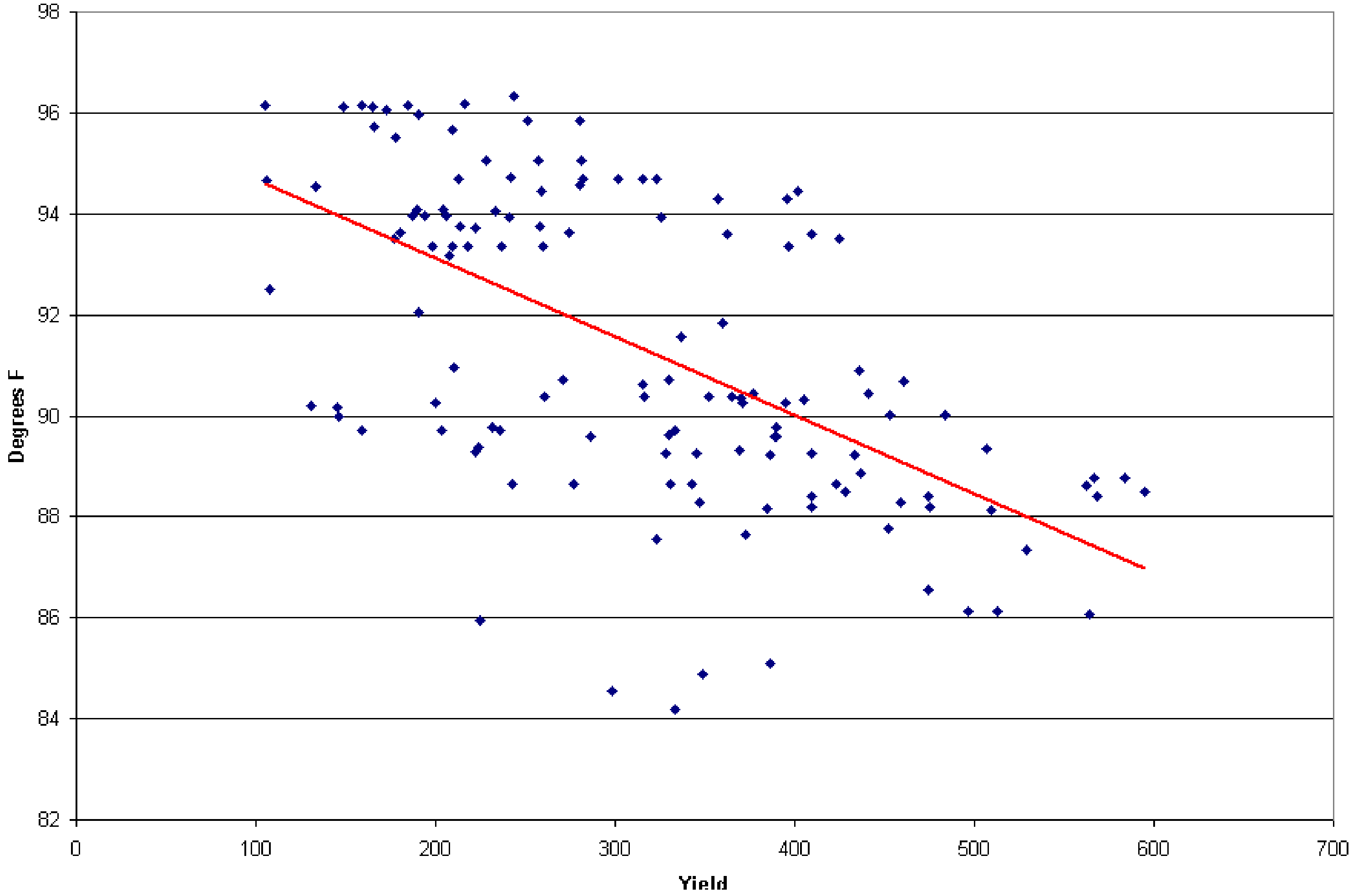


Figure 56: Mature Group 5 Yield versus the Average maximum Temperature in the Seedform – Fullseed Period

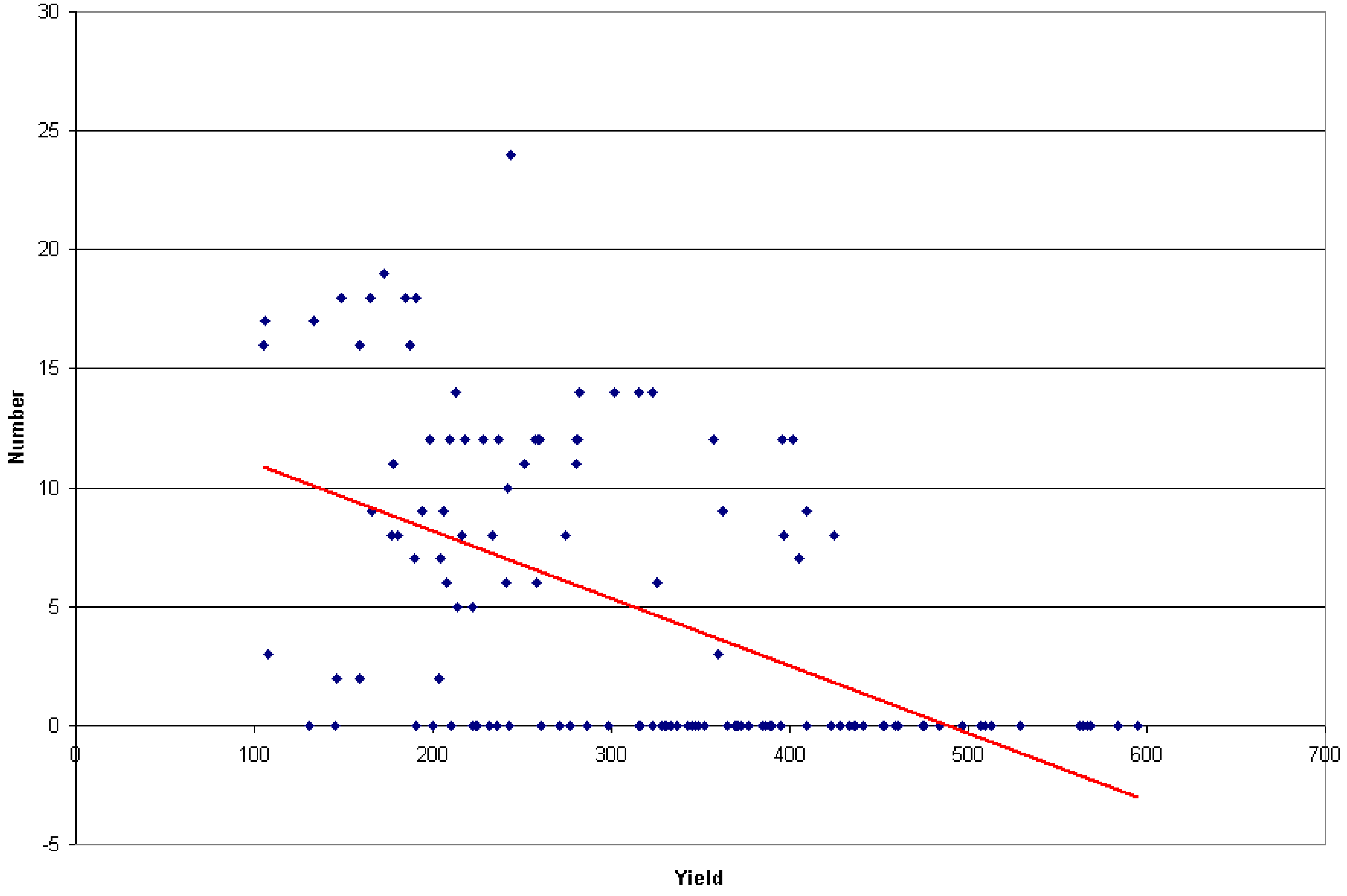


Figure 57: Mature Group 5 Yield versus HT 98s in the Seedform – Fullseed Period

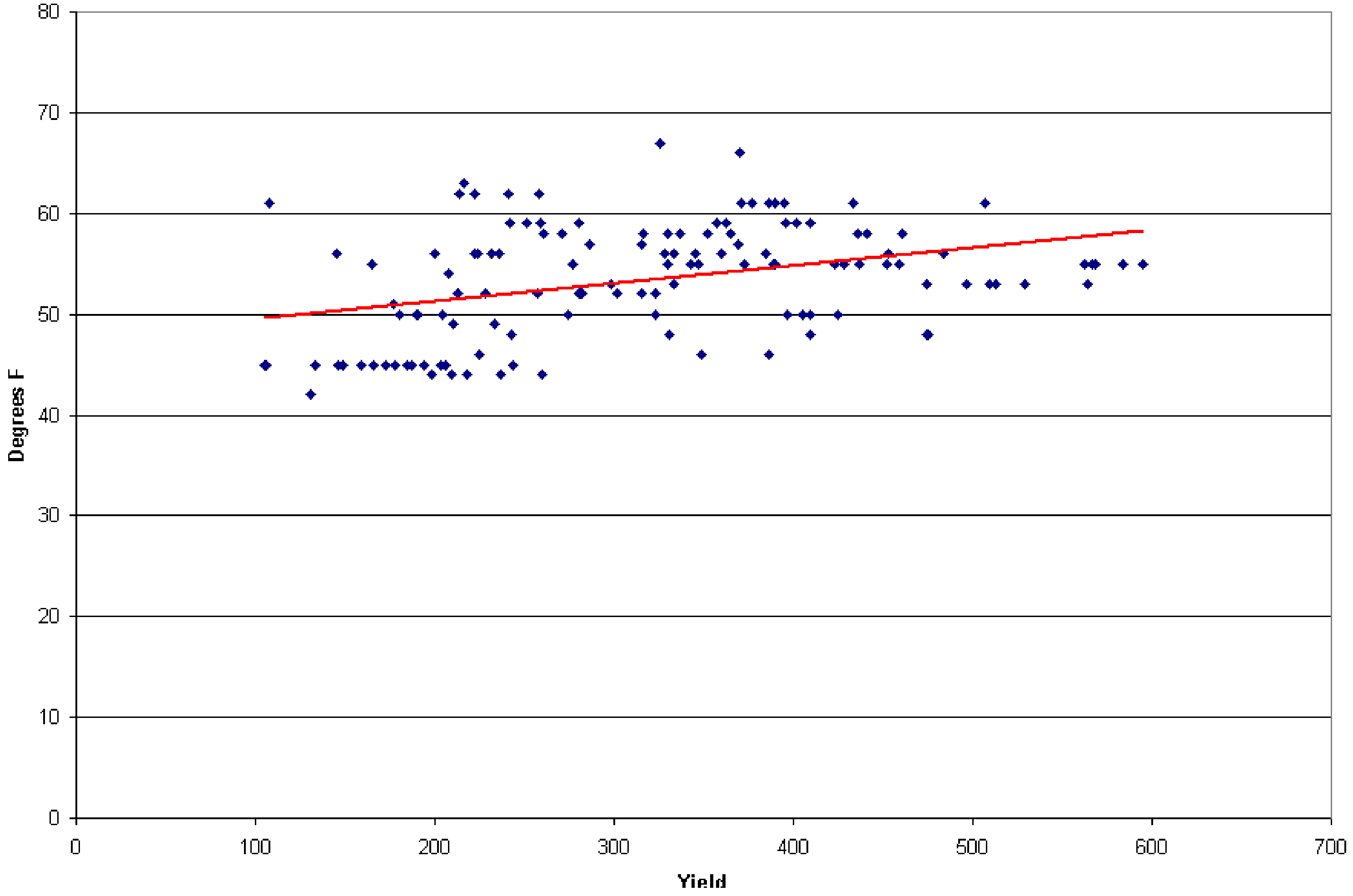


Figure 58: Mature Group 5 Yield versus the Absolute minimum Temperature for the Fullseed – Mature Period

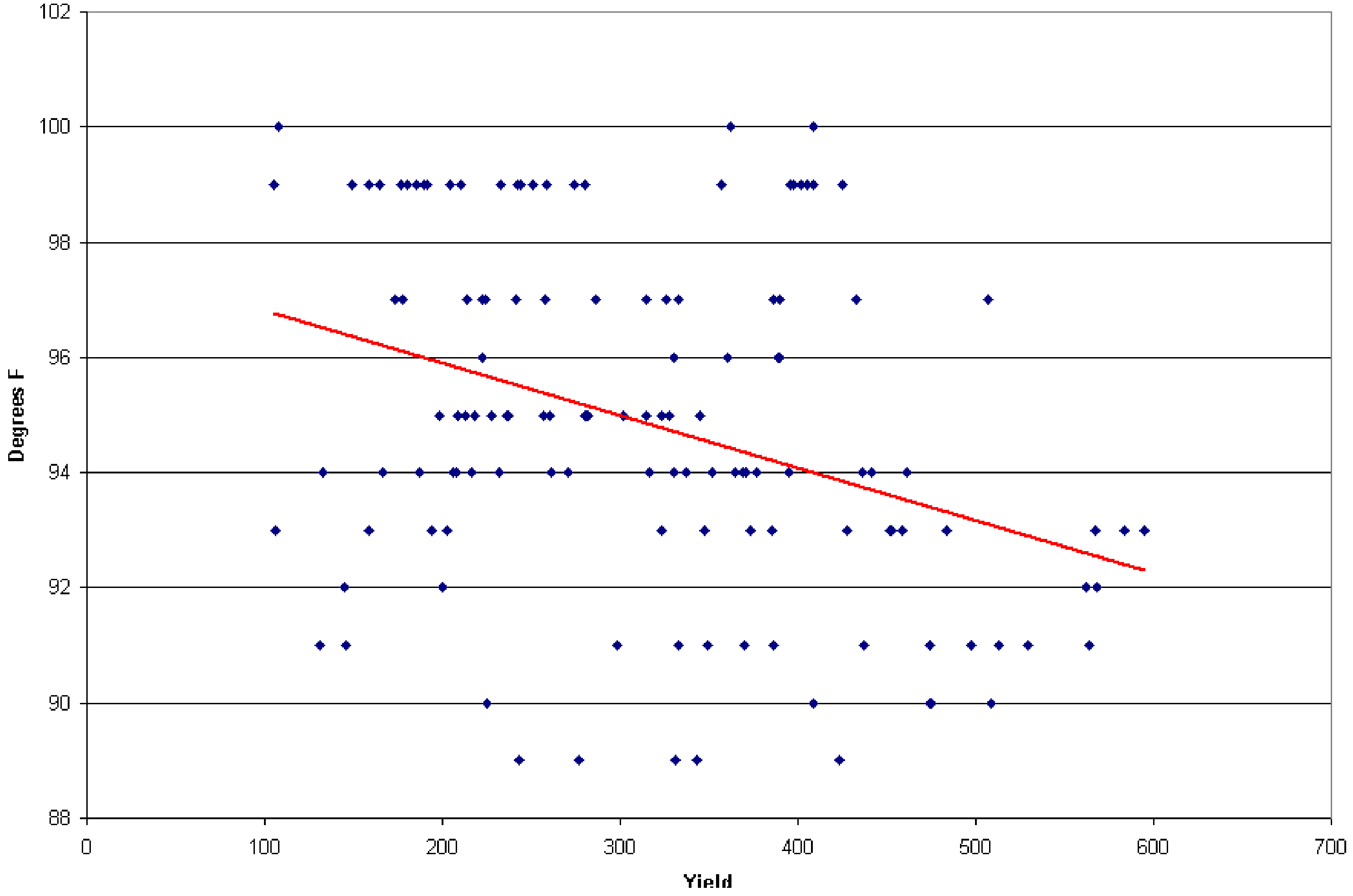


Figure 59: Mature Group 5 Yield versus the Absolute Maximum Temperature in the Fullseed – Mature Period

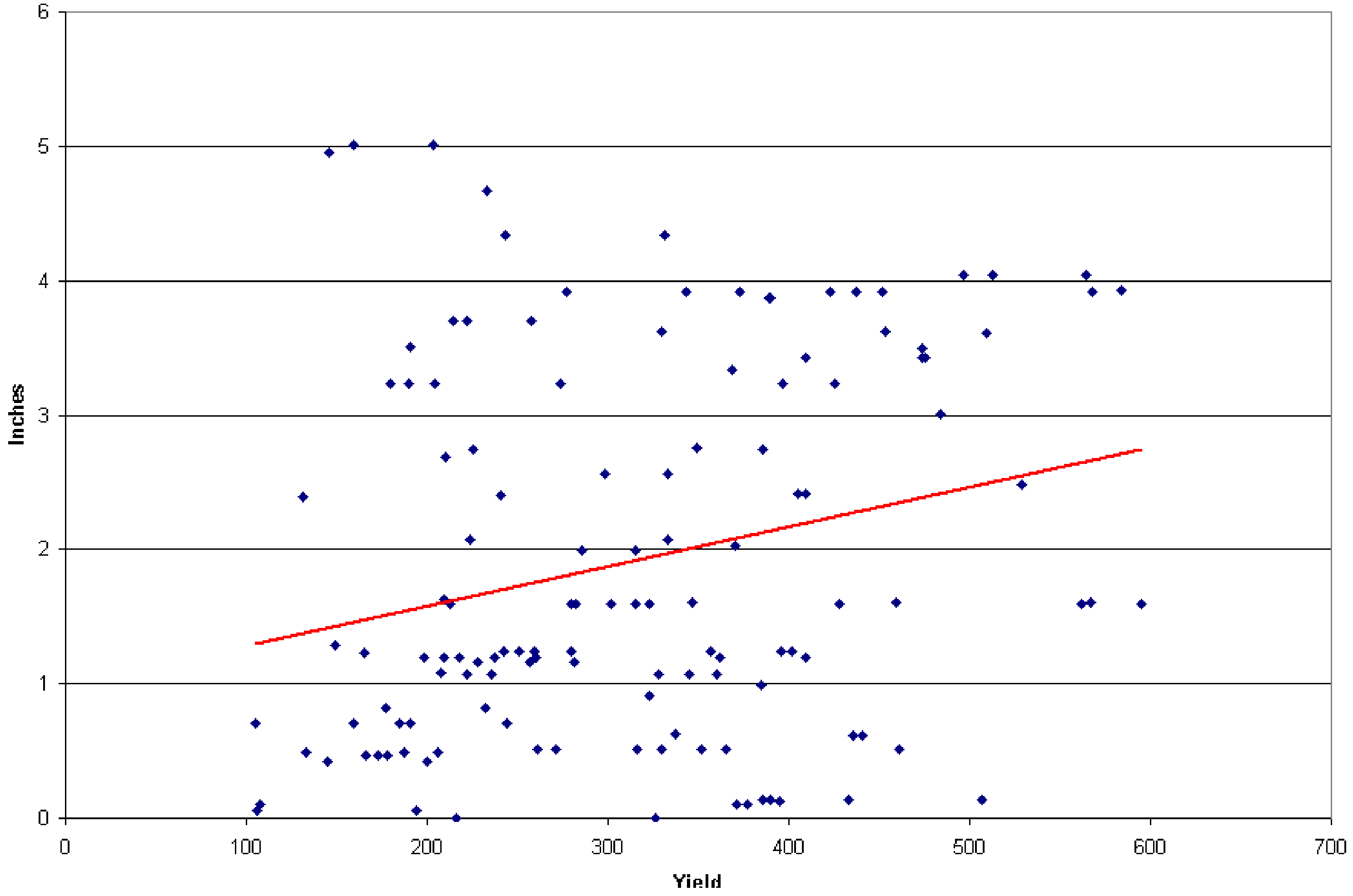
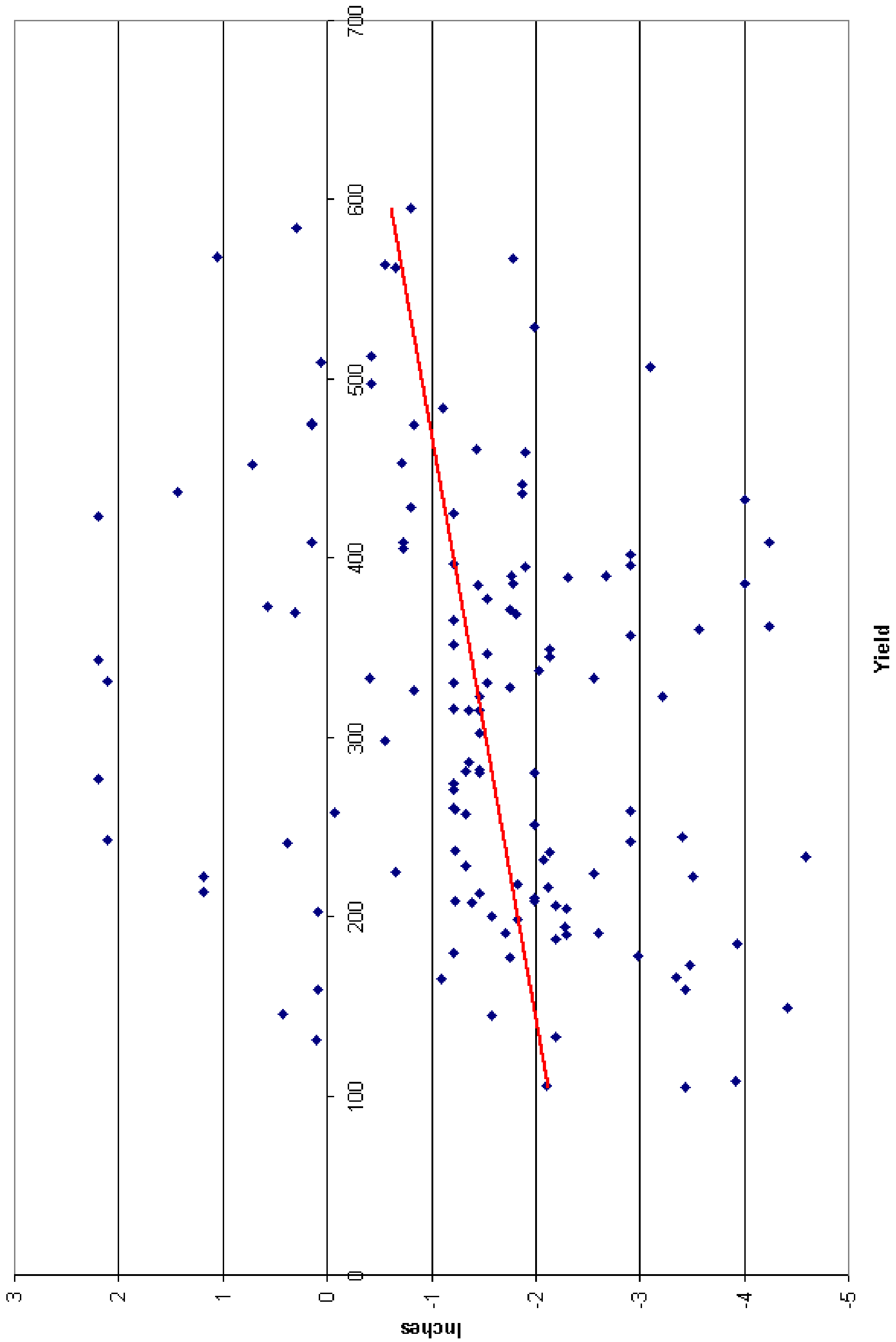


Figure 60: Mature Group 5 Yield versus Precipitation in the Fullseed – Mature Period


3
2
1
0
-1
-2
-3
-4
-5
Inches
0
100
200
300
400
500
600
700
Yield

CHAPTER V

CONCLUSIONS

The objectives of this study were to seek relationships between weather and phenological period length, weather and yield, and phenological period length and yield of soybean crops grown in Mississippi. The objectives have been met, and the hypotheses that there are identifiable relationships between these three sets of factors have been proved true, albeit somewhat less resolutely than anticipated. Of the three objectives, weather and period length demonstrated the fewest strong relationships. More consistent and stronger relationships were found between weather and yield and between phenological period length and yield. Specific, key conclusions as garnered from each of the analyses used to pursue each objective are summarized in the following section.

Specific Conclusions: A Summarized Listing

Objective 1: Weather and Phenological Period Length

Descriptive Statistics

1) There were large variations in growing times in the cases of both Maturity Groups 4 and 5

Correlation Analyses

1) Energy variables dominated over water variables in determining period length, even when using normalized data

Objectives 2 and 3: Weather and Yield and Phenological Period Length and Yield

Descriptive Statistics

Group 4 Total Growing Period

1) An earlier planting date resulted in higher yields
2) A longer total growing period resulted in higher yields
3) Higher amounts of total precipitation and more precipitation days resulted in higher yields
4) Wetter conditions, represented by smaller P-E, resulted in higher yields
5) Fewer +90 days resulted in higher yields

Group 4 Plant-Bloom Period

1) Longer period length resulted in higher yields
2) Higher amounts of total precipitation and more precipitation days resulted in higher yields
3) Fewer +90 days resulted in higher yields

Group 4 Bloom-Podset Period

1) No significant relationships were found

Group 4 Podset-Seedform Period

1) Higher amounts of total precipitation and more precipitation

days resulted in higher yields

Group 4 Seedform-Fullseed Period

1) Higher amounts of total precipitation and more precipitation

   days resulted in higher yields
2) Fewer +90 days resulted in higher yields

Group 4 Fullseed-Mature Period

1) No significant relationships were found

Group 5 Total Growing Period

1) An earlier planting date resulted in higher yields
2) A longer total growing period resulted in higher yields
3) Higher amounts of total precipitation and more precipitation days resulted in higher yields
4) Wetter conditions, represented by smaller P-E, resulted in higher yields
5) Fewer +90 days resulted in higher yields

Group 5 Plant-Bloom Period

1) Fewer +90 days resulted in higher yields

Group 5 Bloom-Podset Period

1) No significant relationships were found

Group 5 Podset-Seedform Period

1) Higher amounts of total precipitation and more precipitation days resulted in higher yields
2) Fewer +90 days resulted in higher yields

Group 5 Seedform-Fullseed Period

1) Higher amounts of total precipitation and more precipitation days resulted in higher yields
2) Fewer +90 days resulted in higher yields

Group 5 Fullseed-Mature Period

1) Higher amounts of total precipitation and more precipitation days resulted in higher yields

Individual Highest and Lowest Yield Cases, Total Growing Period

Group 4

1) Highest yielding case was planted one month before the lowest yielding case
2) Highest yielding case had higher amounts of total precipitation than the lowest yielding case
3) Wetter conditions, represented by smaller P-E, were associated with the highest yielding case
4) Highest yielding case had fewer +90 days

5) Highest yielding case had a lower average maximum temperature
6) Highest yielding case had fewer accumulated HTs (85-98)

Group 5

1) Highest yielding case was planted two and one half weeks before the lowest yielding case
2) The length of the total growing season was longer for the highest yielding case
3) Highest yielding case had higher amounts of total precipitation and more precipitation days than the lowest yielding case
4) Wetter conditions, represented by smaller P-E, were associated with the highest yielding case
5) The highest yielding case had fewer +90 days, fewer HTs, and lower average and absolute maximum temperatures

Correlation Analyses

Group 4 Total Growing Period

1) Higher yields were associated with lower average and absolute maximum temperatures

2) Higher yields were associated with fewer accumulated HT 94s, 95s, and 96s
3) Higher yields were associated with higher total precipitation and more precipitation days
4) Wetter conditions, represented by smaller P-E, were associated with higher yields
5) A longer total growing season resulted in higher yields

Group 4 Plant-Bloom Period

1) Higher yields were associated with lower absolute minimum temperatures
2) Higher yields were associated with a longer P-B period
3) Lower average maximum temperatures were associated with higher yields

Group 4 Bloom-Podset Period

1) No significant relationships were found

Group 4 Podset-Seedform Period

1) Higher yields were associated with higher precipitation and more precipitation days
2) Wetter conditions, represented by smaller P-E, were associated with higher yields
3) Higher yields were associated with lower absolute maximum temperatures

Group 4 Seedform-Fullseed Period

1) Fewer accumulated HTs were associated with higher yields
2) Higher yields were associated with lower average maximum temperatures
3) Higher yields were associated with higher precipitation and more precipitation days
4) Wetter conditions, represented by smaller P-E, were associated with higher yields

Group 4 Fullseed-Mature Period

1) Fewer accumulated HTs were associated with higher yields
2) Lower absolute maximum temperatures were associated with higher yields

Group 5 Total Growing Period

1) Higher yields were associated with lower absolute maximum temperatures and fewer accrued HTs
2) Higher yields were associated with higher precipitation and more precipitation days
3) Wetter conditions, represented by smaller P-E, were associated with higher yields

Group 5 Plant-Bloom Period

1) Lower absolute minimum temperatures were associated with higher yields
2) Lower average minimum temperatures were associated with higher yields

Group 5 Bloom-Podset Period

1) Lower absolute maximum temperatures and fewer accrued HT 97s were associated with higher yields

Group 5 Podset-Seedform Period

1) Fewer accumulated HTs were associated with higher yields
2) Higher yields were associated with higher precipitation and more precipitation days

Group 5 Seedform-Fullseed Period

1) Higher yields were associated with higher precipitation and more precipitation days
2) Wetter conditions, represented by smaller P-E, were associated with higher yields
3) Lower average maximum temperatures and fewer accumulated

   HTs were associated with higher yields

Group 5 Fullseed-Mature Period

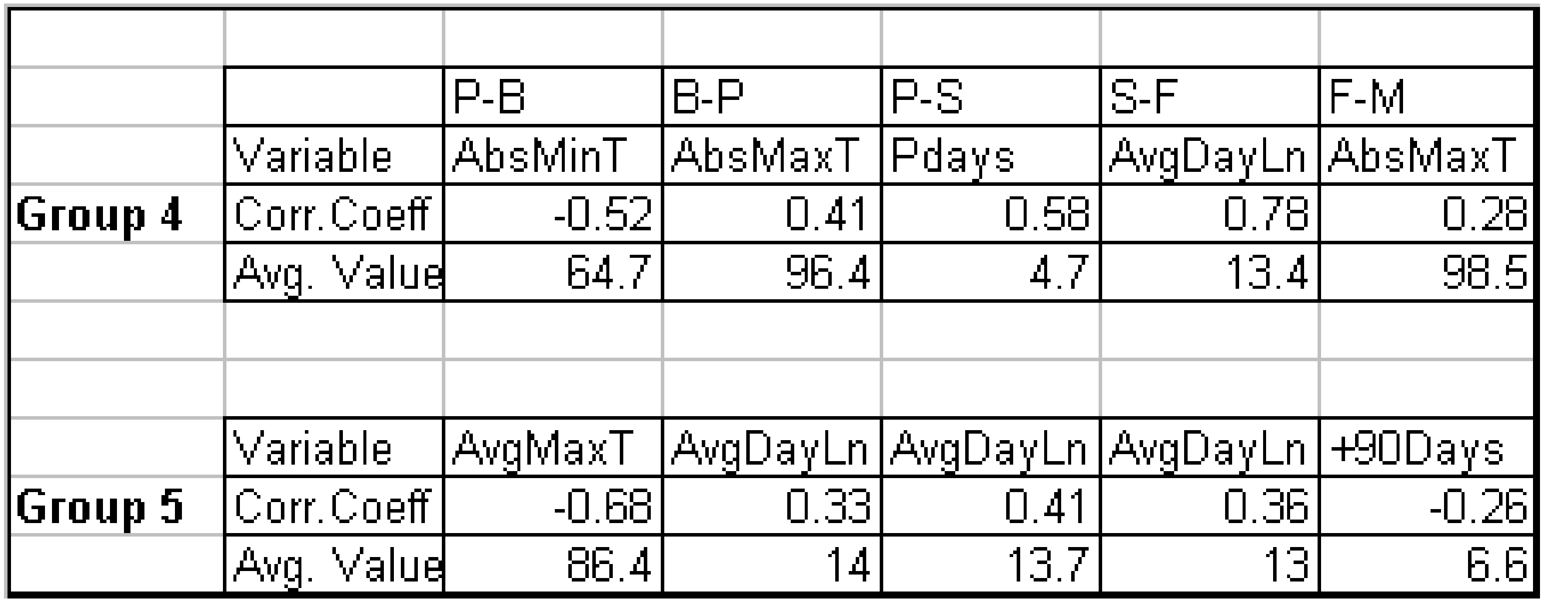
1) Lower absolute minimum and absolute maximum temperatures were associated with higher yields
2) Higher yields were associated with higher precipitation
3) Wetter conditions, represented by smaller P-E, were associated with higher yields

Generalized Conclusions: Weather and Phenological Period Length

The first focus of this project was to determine the impact of weather on the length of phenological periods, not yield, of soybeans in Mississippi. Specific relationships were established, but they were not strong or consistent. Generally it was found that water mattered very little, and that energy variables were more important in determining phenological period lengths. Variation between Maturity Groups 4 and 5 was also found. Table 23 summarizes the results of the analyses, showing for each phenological period of both maturity groups 1) the weather variable that exhibited the strongest control on period length, 2) the correlation coefficient for that variable, and 3) the average value of that variable for each period.

In general, it can be stated that although water is a controllable weather variable through irrigation, this study does not show it to be an important control of phenological period length in Mississippi soybean crops. On the other hand, energy is not a controllable atmospheric input to field crops, but this study shows that the energy variables are more important than water in determining phenological period length in soybeans. The only way to vary the impact of most of the energy variables is to change the planting date.

Table 23: Summary of Analyses for Weather an d Period Lengths



		P-B	B-P	P-S	S-F	F-M
	Variable	AbsMinT	AbsMaxT	Pdays	AvgDayLn	AbsMaxT
Group 4	Corr.Coeff	-0.52	0.41	0.58	0.78	0.28
	Avg. Value	64.7	96.4	4.7	13.4	98.5
	Variable	AvgMaxT	AvgDayLn	AvgDayLn	AvgDayLn	+90Days
Group 5	Corr.Coeff	-0.68	0.33	0.41	0.36	-0.26
	Avg. Value	86.4	14	13.7	13	6.6

Generalized Conclusions: Weather and Yield and Phenological Period Length and Yield

The second and third objectives of this study were to determine what impact, if any, weather and period length had on the yield of Mississippi soybeans. Analyses were conducted to determine during which phenological period a given weather variable (or varying period length) became most important to the overall yield. Descriptive statistics showed that, in both Maturity Groups 4 and 5, higher yields were associated overall and consistently with earlier planting dates, longer growing seasons, lower extreme high temperatures (average maximum temperature, absolute maximum temperature, and HTs), and more total precipitation spread out over more precipitation days.

Correlation and significance analyses showed that overall, for both Maturity Groups 4 and 5, higher temperatures correlated most strongly with lower yields, and those beans that were subjected to less heat stress produced higher yields. Even though the energy variables were more strongly related to yield, the precipitation variables were highly significant overall as well, indicating that the wetter it was during the growing season, the higher the yield.

Correlation analysis also demonstrated that, overall, earlier planting dates and longer growing seasons were also highly significant to yield. This second half of the study showed that soybean yield can be maximized by planting earlier in the growing season when temperatures are not quite as hot, and by irrigating crops during the podset to seedform and seedform to fullseed phenological periods (the periods during which rainfall is most critical to high yields) if rainfall during those periods is not adequate enough to maximize yields. Table 24 summarizes the results of the analyses and shows during which phenological periods the grouped variables (either energy, period length or water) were most important in influencing the overall yield. Differences between the maturity groups may be due in part to the fact that the Group 5 beans were a northern soybean species and the Group 4 beans were a southern soybean species.

It was hypothesized that there is a strong relationship between weather and phenological period length, weather and yield, and period length and yield. Although no consistently strong relationships between weather and phenological period length were made apparent, this study concluded that weather and period length both appear to have an affect on the yield of Mississippi soybeans. In general, higher temperatures tended to depress yields, and although there is no way of controlling this variable, manipulating the planting dates would be one way to subject the soybeans to less heat stress during the hotter portion of the growing season. Precipitation was also important to yield, especially during the podset to seedform and seedform to fullseed periods when higher amounts of precipitation resulted in higher yields. This variable is easily manipulated through irrigation and it is useful to know when during the phenological stages of the soybean irrigation would be most useful. Period length, although not as strongly related to yield as energy or precipitation, did have an affect on yield. The longer the overall growing season, the higher the yields tended to be. In the Group 4 beans, the longer the plant

Table 24: Summary of Analyses of Weather and Yield and Period Length and Yield

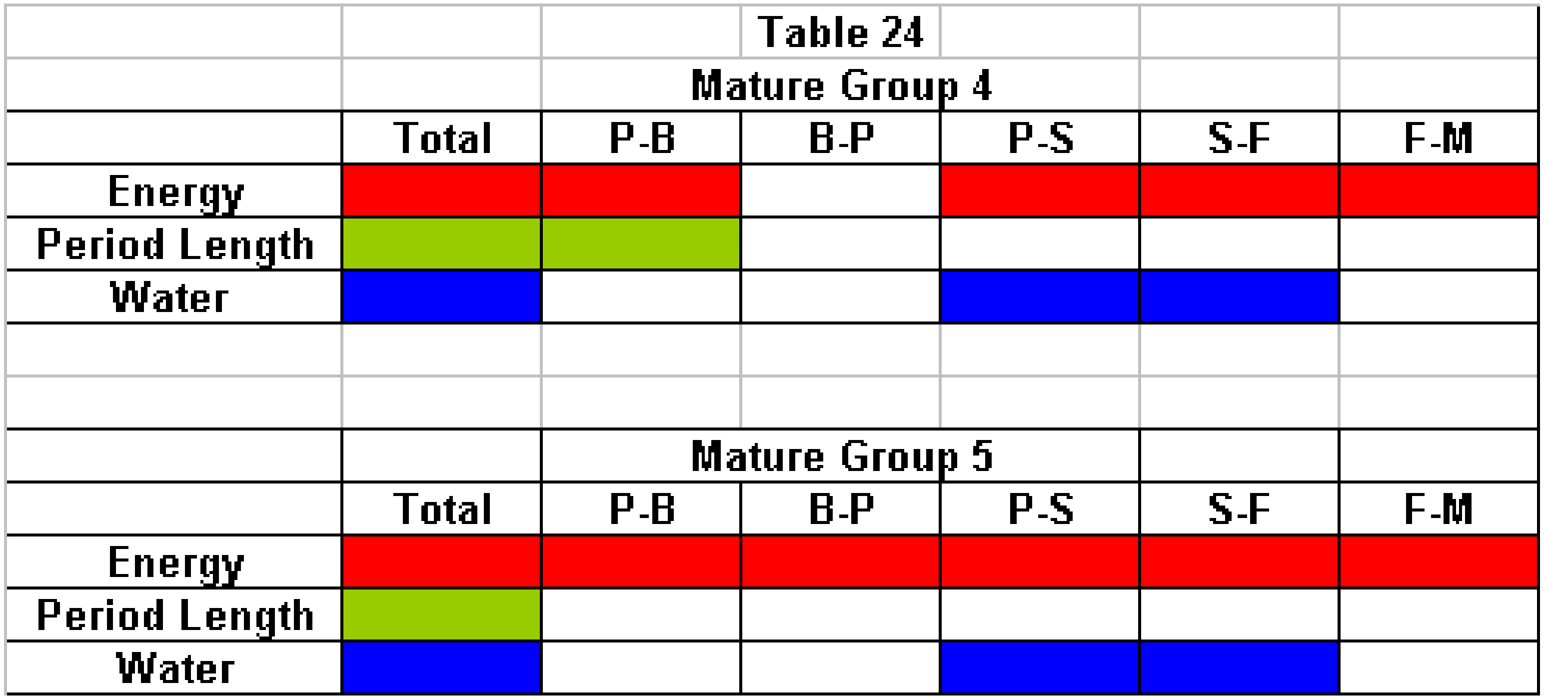


			Table 24			
			Mature Group 4			
	Total	P-B	B-P	P-S	S-F	F-M
Energy	🟥	🟥		🟥	🟥	🟥
Period Length	🟩	🟩				
Water	🟦			🟦	🟦	
			Mature Group 5			
	Total	P-B	B-P	P-S	S-F	F-M
Energy	🟥	🟥	🟥	🟥	🟥	🟥
Period Length	🟩					
Water	🟦			🟦	🟦	

to bloom period was, the higher the yield. This knowledge can be used to make the Mississippi soybean crop higher yielding and therefore, more profitable.

LITERATURE CITED

Critchfield, Howard J. General Climatology, Fourth Edition. Prentice Hall, Inc: Upper Saddle River, 1983.

Diamond, Jared. Guns, Germs, and Steel: The Fates of Human Societies. W.W. Norton & Company: New York, 1999.

Drury, C. F., and C.S. Tan, 1995. Long-term (35 years) effects of fertilization, rotation, and weather on corn yields. Canadian Journal of Plant Science, 75: 355-362.

Griffiths, John F. and D.M. Driscoll. Survey of Climatology. Charles E. Merrill Publishing Co.: Columbus, 1982.

Heatherly, L.G., 2002. Personal Communication, Research Agronomist, USDA-ARS, Crop Genetics and Production Research Unit, Stoneville, MS.

Kincer, J.B. and W.A. Mattice, 1928. Statistical Correlations of Weather Influence on Crop Yields. Monthly Weather Review, 56:53-57.

Logan, J., M.A. Mueller, and C.R. Graves, 1998. A Comparison of Early and Recommended Soybean Production Systems in Tennessee. Journal of Production Agriculture, 11: 319-325.

MASS, 2001. Mississippi Agricultural Statistics, Supplement 34. Mississippi Agricultural Statistics Service, Jackson, MS.

MCES, 2001. Soybeans in Mississippi—Current Situation. Mississippi Cooperative Extension Service, Mississippi State University. http://msucares.com/crops/soybean/index.html.

Mather, John R. Climatology: Fundamentals and Applications. McGraw-Hill Book Company: New York, 1974.

Nowak, Peter, 1998. Thinking about Precision Ag. Successful Farming: @griculture Online, http://www.agriculture.com/technology/thisweek/nowak.html

Pote, Jonathan W., and C. L. Wax, 1986. Climatological Aspects of Irrigation Design Criteria in Mississippi. Mississippi Agricultural & Forestry Experiment Station Technical Bulletin 138, Mississippi State University, Mississippi State, Mississippi.

Sanderson, E.H., 1954. Corn Yield and Climate in the Corn Belt. Geographical Review, 26: 88-102.

Swanson, Earl R. and J.C. Nyankori, 1979. Influence of weather and technology on corn and soybean yield trends. Agricultural Meteorology, 20: 327-342.

Thompson, Russell D. and Allen Perry. Applied Climatology: Principles and Practice. Routledge: New York, 1997.

Wang, J.Y. and R.K. Ray. Agriculture and its Environment: Prediction and Control. Kendall/Hunt Publishing Company: Dubuque, 1984.

Watson, D.J., 1963. Climate, Weather, and Plant Yield. In Evans, L.T. (ed.), Environmental Controls of Plant Growth, 337-349. New York

Wax, Charles L., F. P. Rasberry, and F. B. Matta, 1987. Late Freezes in Mississippi and Their Influence on Peach Crop Damage. Mississippi Agricultural & Forestry Experiment Station Technical Bulletin 148, Mississippi State University, Mississippi State, Mississippi.

Wax, Charles L. and J. C. Walker, 1986. Climatological Patterns and Probabilities of Weekly Precipitation in Mississippi. Mississippi Agricultural & Forestry Experiment Station Information Bulletin 79, Mississippi State University, Mississippi State, Mississippi.