Table of Contents

# WEATHER'S ROLE IN PHENOLOGICAL PERIOD LENGTH OF MISSISSIPPI SOYBEANS: A WATERED-DOWN CONTRIBUTION!

by

Michael E. Brown, Assistant Professor, Department of Geosciences, Mississippi State University

Charles L. Wax, Professor and State Climatologist, Department of Geosciences, Mississippi State University

Jonathan W. Pote, Professor, Department of Agricultural and Biological Engineering, and Associate Vice President for Research, Mississippi State University

## INTRODUCTION

The soybean crop in Mississippi is large and economically important. The state ranks 16th nationally in production of soybeans, with a 1990-2000 average of around 2 million acres planted yearly at an annual value of about $291 million (MASS, 2001). Two recent trends help account for an annual average harvest ranging from 22-26 bushels/acre over this time period: 1) the bulk of beans planted in the state is now in Maturity Groups IV and V as compared to Groups VI and VII in earlier years; and 2) this change has allowed an earlier planting date, mostly before mid-June (MCES, 2001). Earlier planting has been credited with stabilizing soybean production over the last decade (MCES, 2001).

Total seasonal water need for the crop is about 20-25", reaching a maximum peak demand of near 0.25"/day (MCES, 2001). In addition to these known moisture requirements, it is also known that seedbed temperatures between $68^{o}$-$86^{o}$ F are needed for rapid emergence. 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? Can a knowledge of these effects help make production of the crop in Mississippi more precise, dependable, and profitable?

This study's objective is to determine how weather affects the length of five phenological periods of unirrigated soybeans grown in Mississippi. Soybean data were taken from ARS plots of Maturity Groups IV and V grown at Stoneville, MS, using 113 cases of Group IV and 133 cases of Group V beans. No consideration is given to resulting yield, only to length of each phenological period. However, it must be recognized that increased yield is the ultimate objective of understanding the effect of weather on phenological period length. Twelve measured/derived weather variables are used for association with each phenological period. In other words, each phenological period is linked with the actual weather conditions that occurred during that discrete time in an attempt to isolate which weather variables affect period lengths. For that reason, this project segregated 12 weather variables for each of 1230 individual calendar periods. It is hypothesized that the lengths of different phenological stages are to some degree determined by the weather events and conditions occurring during that time.

The value of this research is in the potential for optimizing productivity of soybeans in the state 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. Such a management strategy 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, 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.

## BACKGROUND

This research project evolved from an association between the USDA Agricultural Research Service and the office of the State Climatologist. Phenological growth period data collected by ARS personnel were made available for correlation with historical climate records maintained by the State Climatologist's Office. This collaborative effort allowed a potentially more comprehensive analysis by blending the expertise of two disciplines.

Kincer and Mattice (1928) noted that there were critical periods of soybean growth during which certain weather influences are more marked than during other times. By the 1950s researchers had found that it was advantageous to group soybean growth data by climatically and agriculturally homogeneous regions in order to reduce variability from environmental conditions and more clearly delineate the effects of weather on soybean growth stages (Sanderson, 1954). Odell (1959) used phenological growth stages as specific time intervals. 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. Watson (1963) stated that prediction of yields from weather records could result from detailed knowledge of the ways weather affected certain growth stages of soybeans. All these earlier studies point out the long-held and strong expectation that each stage of soybean growth is influenced by weather.

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.

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.

## METHODS

Data on bean phenological periods were recorded as a part of variety testing conducted at Delta Research and Extension Center, Stoneville, MS, from 1976-2000. Direct field observations were conducted on a daily basis to establish each growth stage. Data collected were variety type, year, soil type, irrigated or not, planting date, bloom date, podset date, seedform date, fullseed date, maturity date. From these dates of developmental stage, phenological period lengths were derived for each experimental crop. Observations showed that the same varieties varied in length of phenological period in different years or because of different planting dates. Environmental factors such as weather were suspected as the primary source of this variation.

Fehr and Caviness (1977) suggested the importance of all researchers using the same terminology of phenological stages in soybean growth. They used a series of vegetative stages (V) beginning with planting but ending before the first bloom appears. This was followed by eight reproductive stages from beginning bloom (R1) through full maturity (R8). Heatherly (2002) combined these into the following five phenological stages, which are used in this study: plant to bloom (P-B); bloom to podset (B-P); podset to seedform (P-S); seedform to fullseed (S-F); and fullseed to mature (F-M).

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 (IV and V), and to those planted only on soil type 1 and not irrigated. 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.

Daily weather records of precipitation, evaporation, maximum and minimum temperature, and day length were put into files constructed to cover the period 1976-2000. These five elements were used alone and in conjunction with seven additional derived variables to produce the weather inputs considered important as forcing factors in phenological period length. The resulting 12 weather variables used for correlation with each phenological period were: 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), and days with maximum temperature above $90^0$ (+90 Days).

The main effort of this study was to associate the beginning and ending dates of each phenological period with the corresponding weather that actually occurred between those dates. This massive 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. The result was 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. Since a longer period length was known to be temporally autocorrelated with totP, Pdays, 0.8PE, P-E, DD50s, DD60s, and +90Days, 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.

Simple descriptive statistics of both raw and normalized values for each of the 12 variables were calculated first (averages, maximum and minimum values, and standard deviations). These were graphed for each of the phenological periods, for both maturity groups, first by raw data and then by derived variables. Next the 12 weather variables 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. These analyses were conducted for both the raw and normalized data.

The 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. Second, the only weather variables considered were the 12 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. Third, possible effects of physiological responses such compensatory growth were not considered. And finally, the weather data were taken from a single point, whereas bean data were taken over large areas.

## RESULTS AND DISCUSSION

Figure 1 shows an example, using case #113 of maturity group IV beans, of the process of establishing the association between weather variables and discrete phenological periods by calendar days. In this case the crop was planted on April 28, 2000. The P-B period lasted 34 days, during which 6.98" of rain fell, evaporation totaled 6.94", daylength averaged 13.7 hours, average maximum and minimum temperatures were 84.5$^{o}$F and 64.7$^{o}$F, respectively. In comparison, the P-S period began on June 26 and lasted only 16 days. TotP was 1.99", .8PE was 3.02", daylength averaged 14.2 hours, and maximum and minimum temperatures averaged 90.5$^{o}$F and 72.1$^{o}$F, respectively. It was apparent that cumulative values, such as totP and .8PE, were integrally linked to period length. In other words, if period length was longer, these totals would invariably be larger. This temporal autocorrelation led to the need for 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 1 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 S-F period as an example, it can be seen that the single value (totP) representing the effect of precipitation over the total period length actually occurred on only two days in the middle of the 37-day period.

Figure 2 illustrates results of the descriptive statistical analyses for five of the measured weather variables. The figure graphically depicts average period lengths, 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 lines for comparison. The impact of the autocorrelation problem is evident, as longer period lengths (e.g., P-B and S-F) tend to show larger summed values of the continuous variables such as 0.8PE. This figure shows that totP decreases though the growing season, while 0.8PE was consistently higher than totP. The pattern of temperatures and daylength is also evident. It is noteworthy that daylength showed little variation throughout all stages of the crop.

Figure 3 shows 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, again).

The average total growth time (cumulative summation of all five period averages) was compared to the longest and shortest total growth times for both groups IV and V. The analysis revealed 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 weather. The times for maturity of the two groups ranged from a low of about 100 days to a high of about 170 days. The average was about 140 days for both.

Results of the correlation analyses for group IV, both raw and normalized data, are illustrated in Table 1. Since temporal autocorrelation was consistently recognized as a source of bias and error, only results of correlations of the normalized data were carried further. Figure 4 summarizes those findings, sorted by the energy, moisture, and combined energy-moisture groups of variables, using the five strongest correlation values (shown in bold numbers in Table 1). 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$^{o}$ variable (N+90Days) was selected to represent the energy group for further analysis.

Figure 5 shows the extreme short and extreme long cases, as impacted by moisture, for group four beans. The relationship between NtotP and period length is shown for each phenological period. The link does not appear to be strong or consistent within or between phenological periods. It is important to note that even the extreme cases fail to demonstrate a clear relationship between water and period length. Figure 6 shows the relationship between N + 90 Days, as an indicator of energy, and the same extreme cases. The only clear association revealed was in the P-B period, when greater energy is linked to shorter period length. No other strong relationships appeared to exist in either group IV or group V.

**CONCLUSIONS**

This project was designed to determine the impact of weather on the length of phenological periods, not yield, of soybeans in Mississippi. Specific relationships that were established were not strong or consistent. Generally it was found that water mattered very little, and that energy variables were more important in determining period lengths. Variation between maturity groups IV and V was also found. Table 2 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 summary, it can be stated that water is a controllable weather variable through irrigation, but this study does not show it to be an important control of phenological period length. On the other hand, energy is not a controllable atmospheric input to field crops, but this study shows the energy variables to be more important than water in determining phenological period length. The only way to vary the impact of most of the energy variables is to change planting date.

One suggestion for continuation of the search for impacts of weather on period lengths is to develop predictive equations through multivariate statistical analyses that more reliably and clearly estimate period length with given weather conditions. Then, by changing the planting dates, different weather scenarios could be used to develop probabilities of different period lengths, which could in turn reveal information on economic aspects of planting date decisions. Knowledge of period length controls could thus be used to aggressively adjust soybean growing season, adding another aspect to precision agriculture in Mississippi.

## REFERENCES


Fehr, W.R. and C.E. Caviness, 1977. Stages of Soybean Development. Special Report 80, Cooperative Extension Service, Agriculture and Home Economics Experiment Station, Iowa State University, Ames, IO.

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.

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/soybeans/index.html.

Odell, R.T., 1959. Effects of Weather on Corn and Soybean Yields. Illinois Research, University of Illinois Agricultural Experiment Station 3-4.

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

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

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

**Table 1: Correlation Matrix, Raw and Normalized Data, Maturity Group IV**

| Group 4 | | | | | |
|---|---|---|---|---|---|
| **Raw Data** | **P-B** | **B-P** | **P-S** | **S-F** | **F-M** |
| **totP** | 0.551549 | 0.590217 | 0.649229 | 0.424131 | 0.200338 |
| **Pdays** | 0.750228 | 0.744743 | 0.775219 | 0.354114 | 0.28196 |
| **.8PE** | 0.924403 | 0.752947 | 0.888457 | 0.908941 | 0.899127 |
| **P-E** | -0.11433 | 0.123272 | 0.308962 | -0.20738 | -0.54117 |
| **DD50** | 0.565545 | 0.798364 | 0.945832 | 0.959146 | 0.900264 |
| **DD60** | 0.261104 | 0.786722 | 0.902066 | 0.92677 | 0.910392 |
| **+90 Days** | -0.01532 | 0.716679 | 0.509228 | 0.644567 | 0.76069 |
| **Normalized Data** | | | | | |
| **AvgMinT** | **-0.45401** | **0.262243** | -0.09001 | **0.396521** | 0.096575 |
| **AvgMaxT** | **-0.44307** | **0.326893** | -0.2197 | 0.109059 | **0.234271** |
| **AbsMinT** | **-0.51709** | 0.070682 | **-0.22035** | **0.232569** | -0.03412 |
| **AbsMaxT** | -0.11891 | **0.409033** | -0.1368 | **0.319704** | **0.281185** |
| **AvgDayLn** | -0.2935 | 0.110243 | **0.359038** | **0.779434** | 0.088292 |
| **Ntotp** | -0.01014 | 0.183301 | **0.484024** | 0.193694 | **-0.20549** |
| **NPDays** | 0.179026 | **0.247129** | **0.584965** | 0.081073 | -0.18366 |
| **N.8PE** | **-0.40826** | -0.02732 | 0.158373 | -0.1094 | -0.01721 |
| **NP-E** | 0.121514 | 0.208118 | **0.396805** | 0.183918 | -0.12291 |
| **NDD50** | **-0.4463** | 0.049591 | -0.19891 | 0.268872 | 0.06727 |
| **NDD60** | -0.432 | 0.109968 | -0.19282 | **0.270959** | **0.201756** |
| **N+90Days** | -0.2393 | **0.319488** | -0.14098 | 0.108859 | **0.217482** |

**Table 2: Summary of Analyses**

| | | **P-B** | **B-P** | **P-S** | **S-F** | **F-M** |
|---|---|---|---|---|---|---|
| **Group 4** | **Variable** | **AbsMinT** | **AbsMaxT** | **Pdays** | **AvgDayLn** | **AbsMaxT** |
| | **Corr. Coef.** | -0.52 | 0.41 | 0.58 | 0.78 | 0.28 |
| | **Avg. Value** | 64.7 | 96.4 | 4.7 | 13.4 | 98.5 |
| | | | | | | |
| **Group 5** | **Corr. Coef.** | -0.68 | 0.33 | 0.41 | 0.36 | -0.26 |
| | **Avg. Value** | 86.4 | 14.0 | 13.7 | 13.0 | 6.6 |

**Figure 1: Example of Period Lengths and Weather Variables, Group IV Case 113 (Planted on April 28, 2000)**

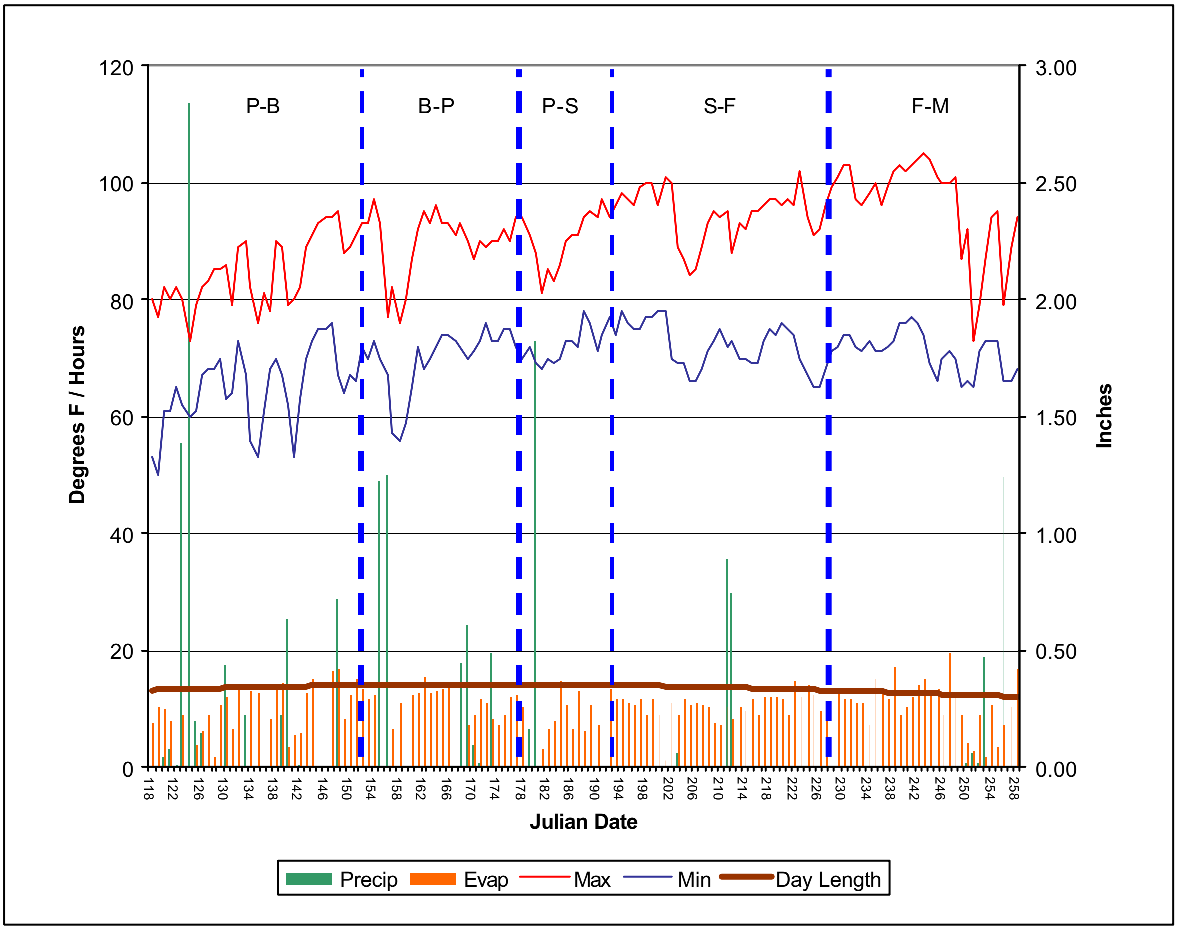

**Figure 2: Average Period Lengths and Associated Average Weather Variables, Group IV (Average Planting Date May 1)**

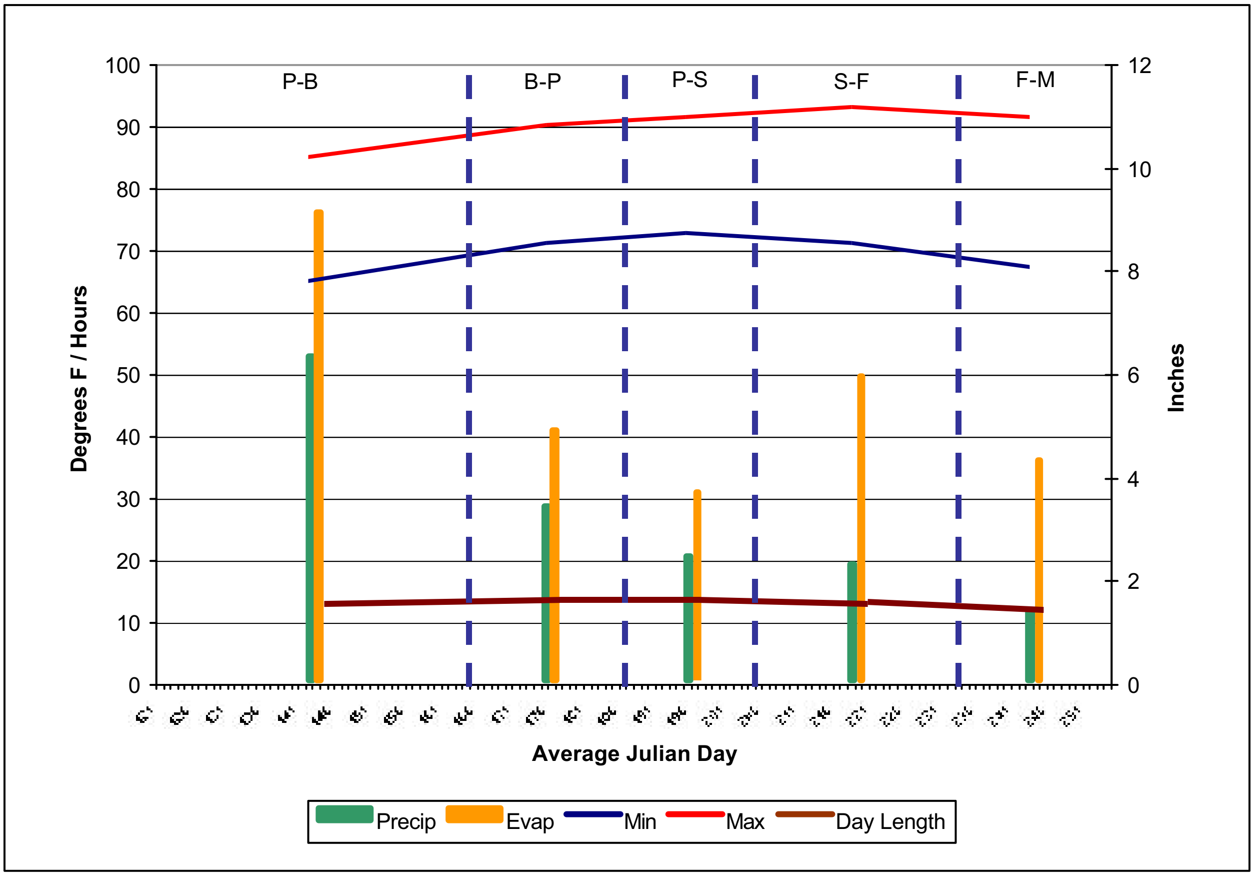

**Figure 3: Average Period Lengths and Associated Additional Average Weather Variables, Group IV (Average Planting Date May 1)**

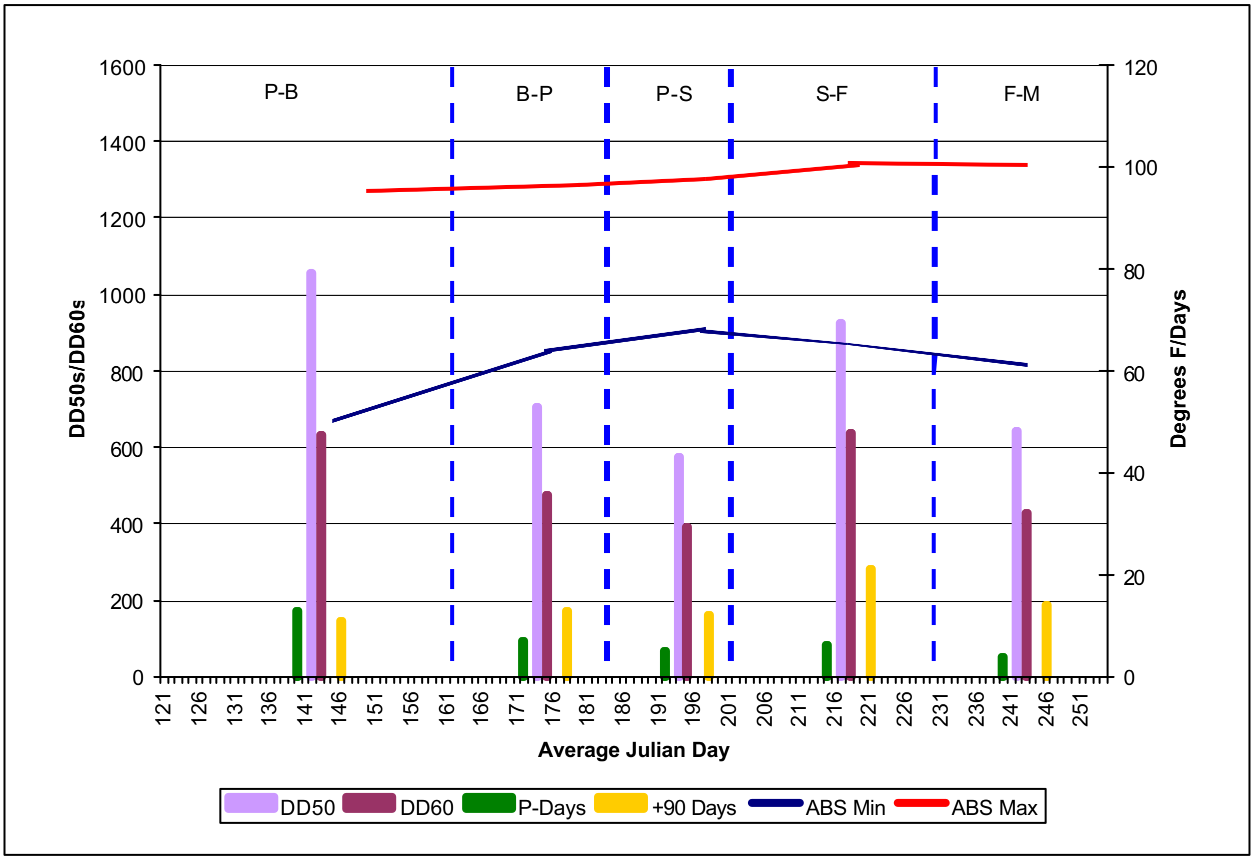

Figure 4: Summary of Correlation Analyses, Group IV, Normalized

| Grp 4 Summary Normalized | P-B | B-P | P-S | S-F | F-M |
|---|---|---|---|---|---|
| N .8PE | -0.41 | | | | |
| N DD50 | -0.44 | | | | |
| N DD60 | | | | 0.27 | 0.20 |
| ABS Min | -0.52 | | -0.22 | 0.23 | |
| ABS Max | | 0.41 | | 0.32 | 0.28 |
| N 90 Days | | 0.32 | | | 0.22 |
| 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 | | |
| N Total P | | | 0.48 | | -0.21 |
| N P Days | | 0.25 | 0.58 | | |

(Orange = Energy Variables, Blue = Moisture Variables, Yellow = Combination Variable)

**Figure 5: Group IV Results: Effects of Moisture on Extreme Period Length**

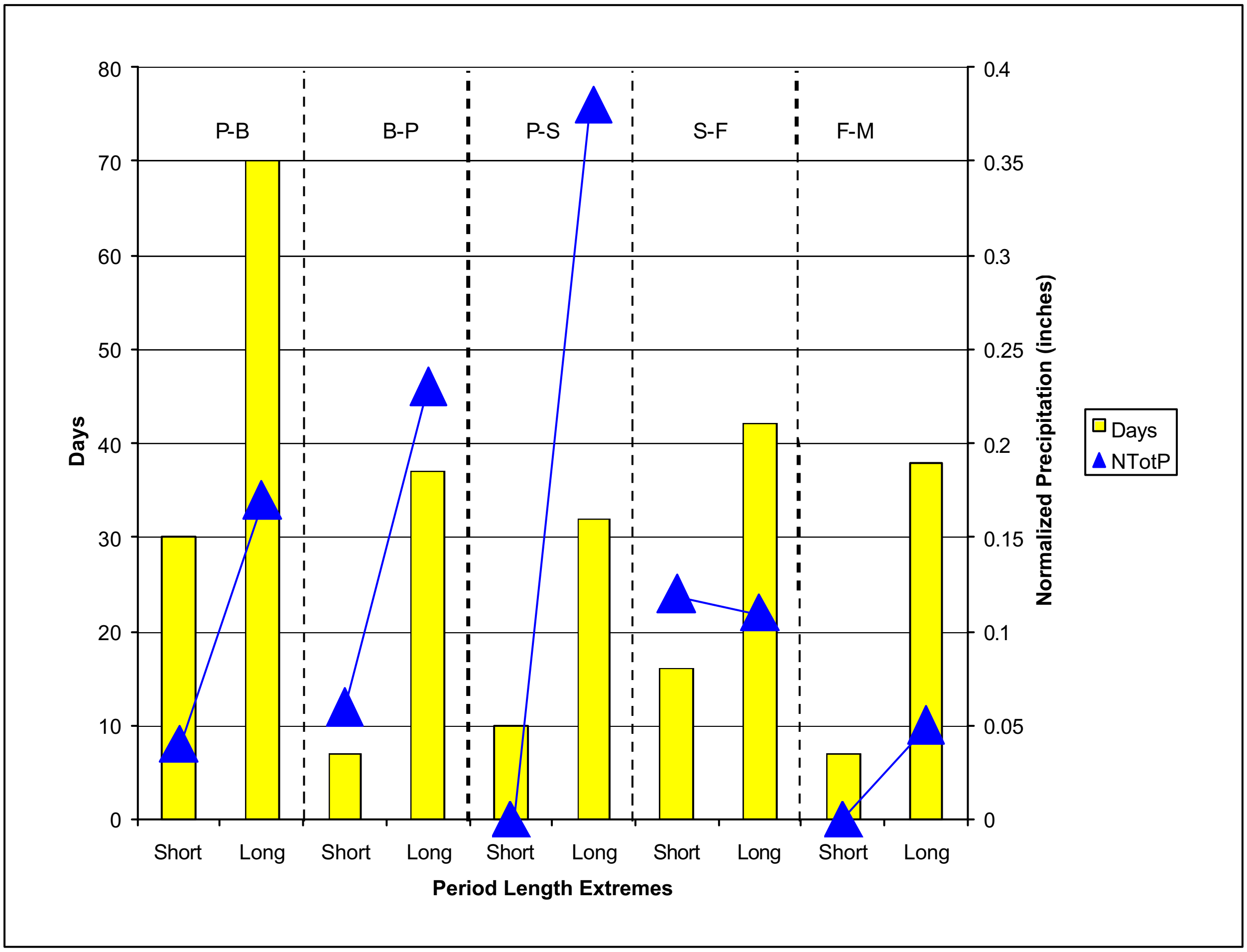

**Figure 6: Group IV Results: Effects of Energy on Extreme Period Lengths**

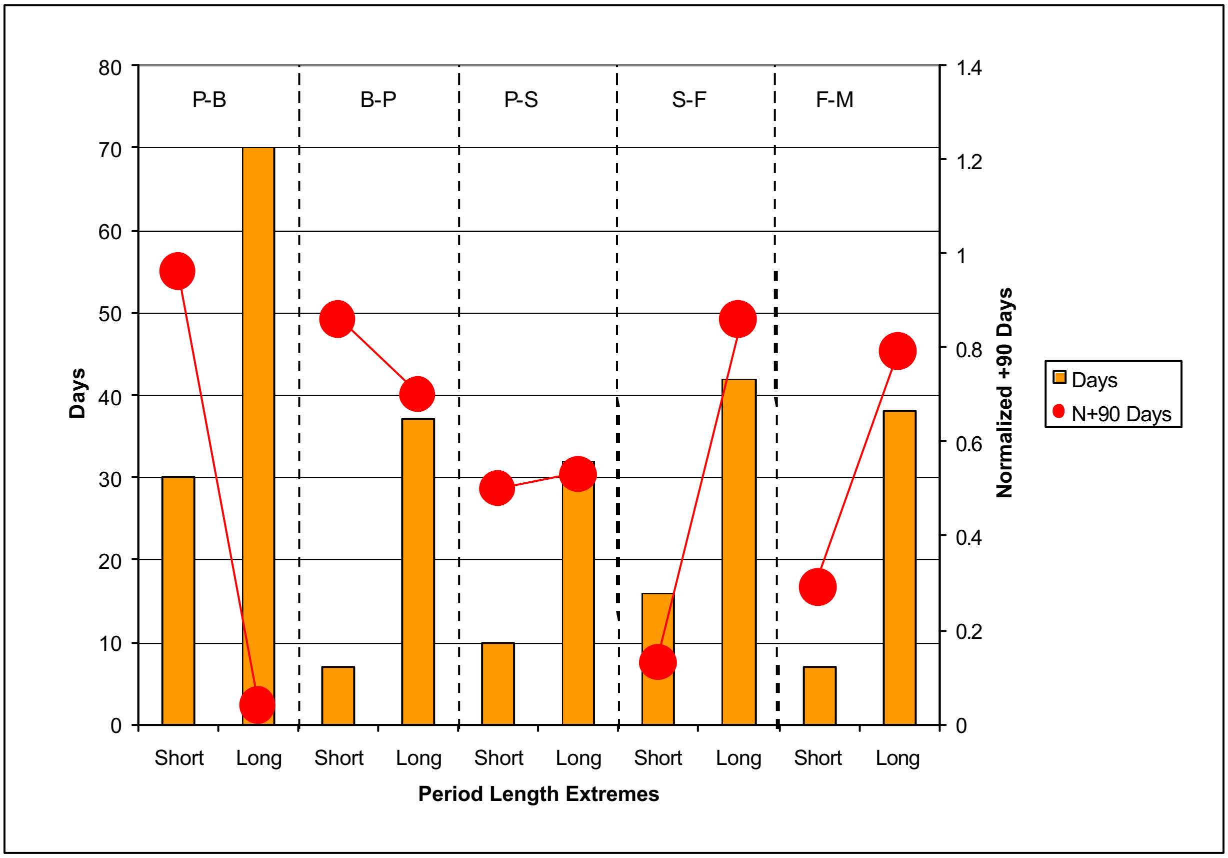


Table of Contents