THE EFFECT OF TEMPERATURE, HUMIDITY, FERTILIZER, SOIL MOISTURE, AND LEAF AREA ON THE SET OF PODS AND YIELD OF WHITE PEA BEANS

A THESIS

Presented to the Faculty of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the Degree of Doctor of Philosophy

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East Lansing

1943

ACKNOWLEDGMENT

The writer wishes to express his appreciation to Dr. C. E. Millar and Dr. R. L. Cook for the valuable assistance and encouragement given throughout the completion of this project.

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INTRODUCTION

The importance of the white pea bean crop in Michigan agriculture is shown by the fact that approximately 87 per cent of all white pea beans grown in the United States are produced in Michigan. Ninty per cent of the total acreage is in 19 counties of central eastern Michigan. Higher average yields of beans are secured from this area than from other areas of the state on soils of equal fertility. This fact together with the inconsistency of results obtained from the use of commercial fertilizers with the crop would indicate that climatic factors are involved in the culture of beans. The results from experiments carried out over a twenty-one year period by members of the Soil Science Section of the Michigan Experiment Station have shown a favorable early response of the crop to commercial fertilizer applications that would be maintained up until the blooming period. However, at harvest time in numerous cases this apparent improvement in the growth of the crop would not be reflected in the yield. In view of this situation the following study was instituted in order to determine the effects of certain climatic factors on the development of the crop, especially during the critical period in which the pods were forming.

REVIEW OF LITERATURE

The effect of environmental factors on the distribution of plant species has received a great amount of attention and a number of broad ecological laws have been formulated. However, work in the field of micro-ecology has not been nearly as extensive. Many reasons for this situation can be enumerated. Among these is the lack of suitable equipment sensitive enough to record micro changes in environmental factors such as relative humidity, air movements, air temperatures, soil temperatures, light intensity, and other factors important in a study of this nature. This type of equipment is relatively expensive as is the equipment required for maintaining constant environmental conditions. This type of investigation requires a considerable amount of tedious labor and the results obtained although very interesting and explaining a number of phenomena, are somewhat impractical since so far very little progress has been made in the field of weather control.

The three most important factors in climate from the standpoint of plant growth are temperature, moisture, and light. The idea in mind in this review of literature is to point out a number of different ways in which climatic factors may influence crop yields and it is not intended to be in any way a complete review of the subject. Only papers dealing with the two factors, temperature and moisture, will be considered since the investigations conducted did not include any direct consideration of the light factor. In any work involving climatic factors it should be pointed out that although climatic factors may be discussed separately there is always an interrelation existing between factors that complicates any single factor relationship.

Hopkins (11) suggests a "bioclimatic" law stating that for each degree of latitude north or south of the equator, and also for each 400 foot increase in elevation the date of flowering of plants of the same species is retarded four calendar days. Likewise, for each five degrees of longitude from east to west on land areas an advance of four days in flowering date results. These values seem to apply to many of our crop plants.

Flowering in tomatoes is largely dependent upon soil moisture and temperature according to Smith (18). Blossom drop is greatly increased by hot dry winds and low humidity as well as a low soil moisture content. A lag of approximately three days exists between the time that temperature exerts an effect on blossom drop and the time the effect becomes visible. An abnormal elongation of the styles of pistils occurs during periods of high temperatures and low humidity.

Temperature is regarded as the controlling factor in the ripening of sweet corn by Appleman and Eaton (1), and, from results of investigations carried out by Suneson and Peltier (19), high daily temperature maxima in conjunction with high radiation appeared to be most conducive to hardening of winter wheat plants provided the hardening took place under the influence of shortening days.

Bair (2) calls attention to differences existing between measurements of climatic factors reported by an official Weather Bureau station and those actually secured from the plots where the data were being taken and suggests that alteration in wind movement, atmometer evaporation, soil temperature and moisture by the plant cover renders measurements of the factors made outside the field of little use in attempts to estimate growth and yield of corn. However, weekly means of air temperature and relative humidity are so little modified by the corn plant cover that weather station records are probably applicable to factor conditions in corn fields for a radius of several miles.

Houseman (12) in a recent publication presents methods for computing weather-yield relationship, and Billings (5) points out the value of careful and systematic use of sound quantitative procedure in the solution of complex problems such as those involved in biological research.

In a discussion of the various methods used in obtaining relative humidity measurements, Thornthwaite and Holzman (21) stress the necessity of careful handling of each type of instrument in order that dependable results may be secured.

Millar et al. (15) suggest that the location of the field bean area in Michigan and the lack of consistancy in response of the field bean to commercial fertilizer applications are due to climatic factors.

The relationship between leaf area and yield of the field bean is small according to the data of Davis (10). In this paper various methods that might be used in estimating leaf area in the field were compared.

From a review of a number of papers published prior to 1920, Brooks (6) finds that a high correlation exists between crop yields and weather factors and that valuable information to the agriculturist may be obtained by predicting crop yields from weather conditions.

The importance of seasonal effect of weather conditions on crop yields has been shown on a number of different crops. Potato yields in Ohio, Smith (17), have been shown to correlate with mean temperature and rainfall and that rainfall is not such a controlling factor as the temperature. Temperatures during June and July and rainfall during July were most important in effecting potato yields. Similarly the seasonal distribution of rainfall in relation to yield of winter wheat, Pallesen and Laude (16), is highly important. Rainfall is of greatest advantage to winter wheat in western Kansas prior to and during the period from seeding to the time wheat enters the winter semidormant stage. Slightly less than average rainfall in early spring is associated with highest wheat yields and above average rainfall is beneficial during the period of rapid stem growth and heading. When predicting corn yields from weather factors, the seasonal distribution, Davis and Harwell (9), of the factors of maximum temperature and rainfall were found to be very important.

The effect of both soil and air temperatures on a number of crops has been reported. Even though bean plants, MacMillan and Byars (14), were not suffering from lack of water, nevertheless, the plants died from the effect of too high a soil temperature. Optimum temperature for potatoes is near 17° C, Bushnell (7), and the detrimental effect of high temperature is largely independent of soil moisture. Excessive respiration may be very generally the limiting factor in plant growth at temperatures above the optimum. This idea of the excessive accumulation according to Thompson (20) of respiratory products is the cause of tipburn of lettuce and that light and low humidity have little influence as causal agents.

High temperature and high soil moisture contents are regarded by Barnes (3) as factors that reduce the carotene content of carrot roots and that temperature and moisture effect the size and shape of the root.

Wheat yields in the Great Plains area are considered by Cole and Mathews (8) to be dependent to a large extent upon the depth of moisture in the soil at planting time and the highest assurance of good yields is afforded by an initial condition of three feet or more of moist soil.

PROCEDURE

Experiments investigating the effect of temperature, humidity, fertilizer, soil moisture, and leaf area on the set of pods and on the yield of the white pea bean were conducted both in the greenhouse and in the field. The temperature and humidity measurements were secured from a Friez recording hygrothermograph which was placed at the same level as the plants were growing both in the greenhouse and in the field.

Soil moisture was determined by drying the soil samples in an oven at 105° C and calculating the per cent of moisture from the resultant loss in weight.

Greenhouse experiments in 1940: leaf area, yield and per cent set of pods were obtained from bean plants grown in one-gallon jars. The six treatments applied to a Miami loam soil were as follows: no fertilizer and 600 pounds of 4-16-8 fertilizer per acre, each at three soil moisture levels, low, optimum, and high. The moisture levels were maintained by bringing the jars to original weight at frequent intervals.

Two glass tubes, three-fourths inch in diameter, were placed one inch and five inches from the bottom of the jars respectively. These tubes had sufficient capacity so that enough water could be added each day to keep the moisture content consistent throughout the jar. Three plants were grown in each jar and two replications of the six treatments were planted at approximately three week intervals from April 6, 1940 to August 1, 1940. In this way the bean plants bloomed over a long period of time in which a variety of temperature and humidity conditions would be encountered. Whenever weather conditions permitted, the plants were removed to a wire enclosed space adjacent to the greenhouse. The leaf area and yield of the individual plants were obtained together with the per cent set of pods and the temperature and humidity data as indicated by the Friez recording hygrothermograph.

Field experiments: Field beans of the Michelite Variety were planted in 28-inch rows for a three year period, 1939, 1940, and 1941, on a Miami loam soil located at the Miller farm, Ovid, Michigan. In order that the blooming period would extend over a longer period of time, plantings were made at approximately five to seven day intervals for a six week period extending from the last week in May to the first week of July. One half of the rows were fertilized with 500 pounds per acre of a 4-16-8 fertilizer placed in a band one inch to the side of and one and three-quarters inches below the seed level. Due to the fact that the hygrothermograph failed to arrive in time to be used during 1939, only yield data from the different planting dates were taken. In 1940 and 1941 just prior to blooming, plants were selected at random from the various treatments and the leaf area was determined according to the method described by Davis (10). The number of leaf areas compiled depended on the amount of help available and with the rapidity at which the plants in the different treatments came into the blooming period. The yields of both beans and straw of these individual plants were taken at harvest time.

The per cent set of pods was secured by attaching a small marking tag marked with the appropriate date just below a pair of blossoms. A few days later a count of the number of blossoms that formed pods was made.

Soil samples for moisture determination were collected at frequent intervals throughout the blooming period.

In 1941 temperature and humidity data were taken at two locations in the bean growing area, one of the locations supposedly more favorable for bean production than the other, in order to have additional information regarding these climatic factors.

From these data the following correlations were made. Leaf area _vs_. yield, yield of straw _vs_. yield of beans, per cent set of pods _vs_. maximum temperature, per cent set of pods _vs_. minimum relative humidity, maximum temperature _vs_. minimum relative humidity, per cent soil moisture _vs_. per cent set of pods, per cent set of pods _vs_. maximum temperature with humidity held constant, per cent set of pods _vs_. minimum humidity with temperature held constant, and per cent set of pods _vs_. maximum temperature and minimum humidity combined.

In addition, the effect of fertilizer on the per cent set of pods was calculated by the analysis of variance and the effect of date of planting and of fertilizer application on the yield of beans were obtained.

A predicting equation of temperature and yield was also calculated from the field data.

EXPERIMENTAL RESULTS

Per Cent Set of Pods, and Temperature and Humidity Relationships in the Greenhouse

The data in Table 1 indicate that no significant correlation exists either between the per cent set of pods and maximum temperature or between the per cent set of pods and minimum relative humidity. However, a significant correlation was found between maximum temperature and minimum relative humidity. These relationships are just the opposite to those found under field conditions. The explanation of these differences is due in part to the smaller number of blossoms tagged. In the greenhouse only 993 blossoms were available as compared to a total of 35,554 blossoms in the field. Due to the inherent variability of individual plants, extremely large numbers should be used in studies of this nature in order to arrive at significant conclusions. Higher maximum temperatures, as high as 110° F compared to a field maximum of 98° F, were encountered under greenhouse conditions, in spite of the fact that the plants were moved in a wire net enclosure adjacent to the greenhouse whenever the weather permitted. The plants were protected from rain in this enclosure in order not to interfere with the different moisture levels. The plants grown in the greenhouse were much smaller and yielded less than plants in the field. The average leaf area and yield for individual plants grown in the greenhouse and in the field were 40.0 and 272.8 square inches and 1.2 and 36.9 grams respectively. With this wide variation in the leaf area and yield between plants grown in the greenhouse and in the field, it would not necessarily follow that the same relationships should exist between the per cent set of pods and maximum temperature or minimum relative humidity for field grown and greenhouse grown plants. Rainfall is another factor effecting plant behavior in the field that is not encountered in the greenhouse thus adding to the variability found between plants grown in the greenhouse and in the field.

Influence of Fertilizer, Date of Planting, and Moisture Levels on Yields in the Greenhouse

The reaction of bean plants to fertilizer, dates of planting, and varying moisture levels is shown by the data presented in Table 2. Significant differences were found between yields from beans planted at different dates and since there is neither a progressive increae or decrease in yields as the date of planting changes, it would indicate the possibility of some climatic factors being responsible for this situation. The increase in yield resulting from fertilizer was very marked and the yields from the jars held at the optimum and high moisture levels were significantly higher than yields from the jars at the low moisture level. The behavior of the bean plants at the three moisture levels was interesting in that average yield from jars held at the high moisture content was significantly higher than the average yield of the jars at the low moisture level, and higher in fact than the yield from the jars in which optimum moisture conditions were simulated. However, the yields from the jars of the high-level moisture content were more variable than yields from jars held at the low and optimum moisture levels. This situation brings up the question as to just what is optimum moisture content. From observation it appeared that the amount of water added to the soil in the greenhouse to have optimum moisture conditions was sufficient since from all appearances the soil was in excellent tilth whereas the soil in the jars held at the high moisture level actually appeared to have nearly reached the point of excess. The soil was very sticky and apparently in poor tilth. However, the bean plants grew well in most cases and on the average out-yielded plants grown at the low and optimum moisture levels.

None of the interactions, dates of planting x moisture levels, dates of planting x fertilizers, or moisture levels x fertilizers, were found to be significant indicating that there was no difference in the way any of the factors reacted to one another. For example, fertilizer increased the yield of beans regardless of the date of planting or the moisture level.

Leaf Area and Yield Relationships Under Greenhouse Conditions

The relationship between leaf area and yield of the field bean under greenhouse conditions is demonstrated in Table 3. Correlation coefficients between leaf area and yield were calculated for fertilized and unfertilized plants planted at different dates and at three moisture levels. The data show that all correlation coefficients calculated, with two exceptions, "May 18, no fertilizer" and "June 18, fertilized", were significant at the 1 per cent level. Significant differences were found between dates in the following cases. Plants not receiving fertilizer, June 18 > May 18; plants fertilized, April 4 > June 18 or May 18; fertilized and unfertilized combined; April 4 and April 16 > May 18 or May 31, and June 18; July 16 and August 1 > May 18 or June 18.

Moisture levels had a variable effect on the leaf area-yield relationship. When the data for both fertilized and unfertilized plants were combined, plants grown at the low and optimum moisture levels showed a significantly higher correlation between leaf area and yield than plants held at the high moisture level indicating that an excess of moisture may tend to unbalance the growth of the vegetative and grain portions of the plant.

Plants not receiving fertilizer had a significantly higher correlation coefficient between leaf area and yield than did fertilized plants indicating that the influence of fertilizer on the rate of growth of the vegetative portion and the production of seed is not of the same magnitude but that the vegetative growth is effected more than the development of seed.

Relationship Between Per Cent Set of Pods and Temperature under Field Conditions

The correlation coefficients and z values calculated for temperature and per cent set of pods relationship are reported in Table 4. The values for r are calculated in six different ways, namely, per cent set vs.maximum temperature on day the blossoms were tagged; per cent set vs. average maximum temperature for the day the blossoms were tagged and for the following day; per cent set vs. the area under the curve as measured with a planimeter taken from the hygrothermograph chart using sixty and seventy degrees as bases for the measurements. The areas secured from both the 60 and 70 degree bases were correlated against per cent set as area for the day the blossoms were tagged and also as the average area for the date the blossoms were tagged and the following day. The idea for using the area under the curve was based on the assumption that an intensity heat factor would be introduced thus resulting in a higher correlation between the per cent set of pods than if maximum temperatures were used solely as a measure. Since a relatively small number of items were correlated the r's were changed to z values (13) in order to determine whether or not any significant differences existed between the correlation coefficients calculated by the various methods. From an examination of the r values recorded in the table, it can be seen that these values are quite different in a number of cases and it would be desirable to know whether or not these differences represented real differences or were the values within the range of experimental error. In no case, according to the z value manipulation, were any of the differences significant. Although the values for r for the most part were higher when areas instead of temperatures were correlated with per cent set of pods indicating some effect due to heat intensity, but since the difference was not found to be significant the average maximum temperature for the two successive days was used later in calculating the multiple and partial correlation coefficients. Considerable time is required to obtain the planimeter measurements, and according to the data, the results did not warrant the additional effort.

Relationship Between Per Cent Set of Pods and Relative Humidity under Field Conditions

The data in Table 5 show that there is a significant relationship between the per cent set of pods and minimum relative humidity. However, minimum relative humidity does not exert as great an effect on the set of pods as does maximum temperature. The data also show that using the area under the curve, as measured by a planimeter, taken from the hygrothermograph chart should not be used since a negative correlation is obtained rather than a positive correlation when the minimum relative humidity figure is used. There is no advantage in using an average of the minimum relative humidity for the date the blossoms were tagged and for the following day as compared to using the minimum humidity value for the date the blossoms were tagged.

Relationship Between Maximum Temperature and Minimum Relative Humidity under Field Conditions

The correlation existing between maximum temperature and minimum relative humidity expressed as correlation coefficients and z values is reported in Table 6. The correlation coefficients were calculated in two ways for each of the two years 1940 and 1941 and for the combined data for the two years. The average maximum temperature for two successive days was correlated first, against the minimum relative humidity for the date the blossoms were tagged and second, against the average minimum relative humidity for the date the blossoms were tagged and for the following day. Significant values of r were obtained when the data for the two years were combined. As shown by the corresponding z values there was no significant difference between either of the two methods used indicating no advantage in averaging the minimum relative humidity for the two days. The data show that a significant correlation of -0.4664 exists between maximum temperature and minimum relative humidity for the years 1940 and 1941. The degree of relationship between maximum temperature and minimum relative humidity is not as great as between the per cent set of pods and maximum temperature.

Multiple and Partial Correlations Between the Per Cent Set of Pods and Maximum Temperature and Minimum Relative Humidity

The multiple correlation calculated between the per cent set of pods and the factors of maximum temperature and minimum humidity reported in Table 7 indicates a high degree of relationship. The average maximum temperature for the two successive days and the minimum relative humidity for the date the blossoms were tagged were used in calculating both the multiple and partial correlation coefficients. With humidity held constant there is still a significant correlation between per cent set and temperature. However, with temperature held constant the humidity effect is not great enough to be significant indicating that maximum temperature is the most important climatic factor effecting blossom development of the field bean.

Predicting Per Cent Set of Pods from Temperature

The predicting equation of temperature and per cent set of pods, found in Table 8 indicates that approximately fifty-seven per cent of the blossoms will set pods if the average maximum temperature for any two successive days during the blooming period does not exceed 75°F. For each degree of temperature above the 75 degrees a reduction of approximately two per cent in the set of pods will result. However, it should be remembered in using a predicting equation of this kind based on one climatic factor that there are a number of inherent errors that could be encountered for any specific time. For example, it has been repeatedly shown (3) (7) (14) (18) that other climatic factors such as soil temperature, soil moisture, relative humidity, and light intensity do influence plant behavior thus tending to decrease the accuracy of a single factor prediction. Another important fact that is very difficult to estimate is the lag in the time that it takes for a change in temperature to manifest itself appreciably in the plant development. It has been observed in working with bean plants that after a few days of high temperatures it requires some little time for the plants to recover sufficiently to take full advantage of a period of optimum temperature for set of pods. Another case that lowers the correlation between maximum temperature and per cent set of pods is the situation in which a day with optimum temperature occurs in a period of prevailing high temperatures. Here again the full advantage of an increase in the per cent set of pods that would be expected if temperature alone were the only factor is not attained.

In addition, strict linearity of the data is assumed and in this respect it should be pointed out that this equation is only applicable within the range of temperature of 55 to 98 degrees encountered in the investigation. Predicting the per cent set of pods from temperatures outside this range could easily lead to erroneous results.

Temperature and Relative Humidity Variations with Respect to Locality

The data in Table 9 show that the average maximum daily temperature is significantly lower and the average minimum daily relative humidity significantly higher at the Horst farm than at the Miller farm during the blossoming period of the field bean during 1941. Although these data are only for one year, nevertheless, they are based on daily records for two different periods from July 14 - August 31 and from July 14 - August 17. Lower temperatures prevail as a rule during the last two weeks in August than during the previous four weeks so the two periods were selected in order that the differences in temperature and humidity might be accentuated thus preventing the possibility of the lower temperature, that might be encountered if the last two weeks in August were included, detracting from the final conclusion. Also the last two weeks in August do not represent the time when the blossoming period is at its height. The mean differences for both temperature and minimum relative humidity are significant at the 1 per cent level in all cases with the one exception, the mean difference for relative humidity for the July 14 - August 17 period, and in this case the measure of significance is well above the 5 per cent level. Since it has been shown that after the maximum temperature has reached 75°F the per cent set of pods rapidly decreases and that there is also some relationship between per cent set of pods and minimum relative humidity then an area in which lower maximum daily temperature and higher minimum relative humidity prevail would be more favorable for this crop providing soil conditions were comparable. This assumption is born out very well by the facts of the case since the Horst farm is in the center of the best bean growing area in the state and the Miller farm is outside of this area.

Influence of Soil Moisture on the Per Cent of Set of Pods

The effect of soil moisture content on the per cent set of pods is reported in Table 10. According to these data neither the per cent moisture in the surface six inches nor in the subsoil had any significant effect on the per cent set of pods.

Influence of Fertilizer on the Per Cent Set of Pods under Field Conditions

According to the data in Table 11 an application of 500 pounds of a 4-16-8 fertilizer applied in a band 1 inch to the side and 1 3/4 inches below the seed had no effect on the per cent set of pods for either the 1940 or 1941 seasons. However, the difference in the per cent set of pods at the various dates was highly significant, indicating again the role of climatic factors in the production of the field bean.

Influence of Fertilizer and Date of Planting On Yield of Beans Obtained in the Field

The data in Table 12 show that 500 pounds of 4-16-8 fertilizer applied to a bean crop in 1940 significantly increased the yield regardless of the planting date and that the yields of beans for both the earliest and latest planting dates, May 31 and June 12 respectively, were significantly higher than the yields secured from either of the plantings made on June 3 or June 9. It is interesting to note in this respect that the yield from the planting made on June 6 was not significantly higher or lower than any of the other yields indicating the possibility that differences in yield found at different dates of planting which can be considered as synonymous to a different time of blossoming are due to the weather conditions prevailing during the blooming period.

Influence of Fertilizer on Leaf Area and Yield of Grain and Straw under Field Conditions

The data in Tables 13 and 14 show that an application of 500 pounds of 4-16-8 fertilizer caused significant increases in leaf area and yield of both straw and grain of individual bean plants in some cases. These increases were more consistent for the 1941 season than for the 1940 season. In 1940 in only one case in five did a significant increase in either the yield of grain or straw result from an application of fertilizer. However, in three cases in five a significant increase in leaf area was observed. For the 1941 season in all cases significant increases in yield of straw and leaf area resulted from a fertilizer application and in three out of four cases the yield of grain was significantly better. These data indicate a considerable seasonal effect in plant behavior toward fertilizer application. It is interesting to note that the significant differences found in 1940 were only significant at the 5 per cent level. However, in 1941, all differences bound to be significant were at the 1 per cent level. This situation may be partially due to the fact that during the 1940 season the plants were spaced closer together than in 1941. In 1941 the plants were thinned to approximately eight inches apart and in 1940 to four inches apart. The greater competition between plants in 1940 than in 1941 may be in part responsible for the difference in the consistancy of response to fertilizer.

The effect of date of planting on the leaf area and on the yield of both straw and grain is noted in the wide variation between the values for the different planting dates. In 1940 the leaf area ranged from 201.2 to 474.4 square inches for plants receiving fertilizer and from 154.9 to 406.2 square inches for plants not receiving fertilizer. Similar variation in both the yield of grain and straw were found. The variations in leaf area, and grain and straw yields were not as wide during the 1941 season as in 1940 again bringing out the seasonal effect.

Leaf Area and Yield Relationships Under Field Conditions

The data in Tables 15 and 16 show the relationship between leaf area and yield of seed and weight of straw and weight of seed for individual plants grown in the field in 1940 and 1941. The correlation coefficients calculated for the various planting dates may be either significantly positive or significantly negative depending on conditions showing that very little correlation exists between leaf area and yield of the field bean. However, the relationship between yield of seed and straw is highly significant with each planting date in 1940 and in five out of eight cases in 1941 indicating that the weight of straw is a better measure of the yield of seed than the leaf area. Fertilizer does not seem to have any consistant effect on the relationship of leaf area and yield of seed or weight of straw and weight of seed.

Discussion of Results

In a study of factors influencing the development of the field bean plant, the effects of temperature, humidity, soil moisture, fertilizer, and leaf area were included. In addition to these factors there are a number of others that are also involved. Included in these factors are wind velocity, amount, distribution, and intensity of rainfall, degree of cloudiness, and plant cover. These factors are of especial significance during the blossoming stage. A short discussion of the possible ways that these additional factors might influence the bean plant together with a few remarks on the growth habit of the plant may aid in explaining more completely some of the results secured.

The recommended planting date for beans is during the first ten days in June and harvest begins approximately three months later. Blossoming begins six to seven weeks after planting, starting at the lower part of the plant and progressing toward the tips of the branches including blossoming of the runners providing weather conditions are favorable. The plants may blossom and set pods and continue to bloom for as long as five or six weeks if a wet period occurs late in the season thus causing a situation in which there are ripe pods present and blossoms forming at the same time. In case an early frost comes, a number of the immature pods formed during this late blooming period will be damaged and the resultant quality of the crop appreciably lowered. The length of the blooming period makes it possible to get a fair yield even though the weather conditions during part of this period are unfavorable.

It has often been observed that during days of high temperature and low relative humidity, and if the wind velocity is high, a much lower per cent set of pods is obtained than under similar conditions of temperature and humidity but with wind velocity low. In fact, farmers associate these hot dry winds with "blasting" of the blossoms. Wind velocity, then, can be a contributing factor in the set of pods thus modifying the factor of temperature alone.

Rainfall is also an important factor as, in addition to supplying soil moisture, it exerts a mechanical effect on blossom development.

During heavy rains, the blossoms on the tips of branches or runners are driven into the ground thus reducing the set of pods. During periods when the surface of the soil is kept moist many of the blossoms that touch the ground actually rot and thus fail to form a pod. Therefore, intensity and amount of rainfall effect the per cent set of pods independently of temperature thus reducing the degree of correlation between temperature and set of pods. Usually, a wet period is associated with temperatures most favorable for pod formation and in this way the advantages possible from favorable temperature are not fully realized because of the unfavorable effect of excessive moisture.

The degree of cloudiness exerts a slight effect on the set of pods by modifying the temperature and light effects. For example, if the maximum temperature is used in correlating temperature and per cent set of pods, then, during a cloudy day the length of time that the maximum temperature would effect the plant would be less than during a clear day with the same temperature, and the per cent set of pods for each day would be different.

Temperature is the climatic factor that influences the per cent set of pods to the greatest degree. According to the experimental results obtained, a significant correlation exists between these two factors, and the per cent set of pods can be predicted with a fair degree of accuracy from maximum temperatures. The error for any single predicted value is 7.6 per cent of the mean. This error is quite large but in consideration of the fact that temperature is only one of the factors involved the magnitude of the error is well within the expected. This demonstrated temperature effect brings out the practicality of this type of study in determining whether or not any particular location would be suitable for the production of field beans. Significant daily temperature differences found in 1941 between two farms one located in the typical bean area and the other just outside this area, add considerable weight to the data since here is a practical demonstration of conditions actually existing in the field for which a plausible explanation can be offered. The inconsistancy of seasonal response of the field bean to fertilizer can be largely explained on the basis of temperature influence. In spite of the fact that the fertilizer stimulates the vegetative growth, unless favorable temperatures prevail during the blooming period, a poor yield will result. It has often been observed that fertilizer will hasten the blooming period just enough so that the majority of blossoms form during a hot dry period and no yield increase results from the use of the fertilizer. The effect of date of planting is shown in Figure 1. There is just one week's difference in the date of planting, nevertheless, the plants in one case are well podded while in the other they are practically devoid of pods.

Compared with the effect of maximum temperature the effect of minimum relative humidity on the per cent set of pods is of minor importance although a significant correlation was found between these two factors. In general high maximum temperature is associated with low relative humidity but this association was not found to be significant under the field conditions experienced in this investigation unless the two years' data were combined. However, it was found that the average minimum relative humidity during the blooming period was significantly higher on a farm located in the typical bean area than on another farm outside of this area, indicating a tendency for humidity to influence plant behavior.

The per cent set of pods was not found to be associated to any appreciable degree with soil moisture changes. However, the data should be interpreted as meaning that the amount of moisture found in the soil did not reach a critical point either from the standpoint of an excess or a too limited supply. In other words, the data apply only within the limits encountered in the experiment because it is self evident that any portion of a plant will not develop naturally if either an excess or limited amount of moisture is available.

In studies of this nature, it is essential that the weather recording instruments be placed in the area where the experiment is conducted and at the same level as the plants are growing. Weather data supplied by a weather station even in the general vicinity cannot be depended upon to simulate the conditions found at the experimental location. The modifying effect of the plant cover is not accounted for in weather data obtained in other than the same location in which the plants under experimentation are growing.

The data secured from this study show that results obtained in the greenhouse differ from those obtained under field conditions. For example, individual plants grown in the field had on the average thirty-one times more seed and seven times more leaf area than plants grown in the greenhouse. These data show that the ratio of seed to straw varies widely in plants grown under different conditions. There was no significant correlation between maximum temperature and per cent set of pods or minimum relative humidity and per cent set of pods in the greenhouse. However, the correlation between maximum temperature and minimum relative humidity under greenhouse conditions was found to be significant. The reverse of these relationships was found in the field. According to the results of this study, the assumption that results obtained in the greenhouse in an investigation of this nature are applicable under field conditions is subject to criticism.

It might be assumed that the extent of leaf area of a plant would influence the yield since the ability of a plant to manufacture food increases with greater leaf area. However, the data obtained in this study do not show that this relationship is at all constant. Depending on the weather conditions at the time of pod formation, the correlation between leaf area and yield may be either positive or negative. This situation, then, implies the existence of other factors that influence the ratio of the yield of seed to leaf area. As the plants were grown within a limited area of the same soil thus excluding the factor of soil fertility, the factors remaining would of necessity be climatic. As shown by the data the temperature during the blossoming period is the most important climatic factor involved.

Summary

The effects of temperature, humidity, soil moisture, leaf area, and fertilizer on the behavior of the field bean were investigated both in the greenhouse and in the field.

Maximum temperature influences the per cent set of pods more than any other of the factors studied and the per cent set of pods can be predicted from maximum temperature with a fair degree of accuracy.

Minimum relative humidity and soil moisture, within the limits encountered in the work have minor influence on the per cent set of pods.

Fertilizer had no effect on the per cent set of pods.

Plants grown under greenhouse conditions encountered in the experiment did not respond the same to environmental factors as did plants grown under field conditions.

The relationship of leaf area to yield of seed may range from a positive to a negative correlation depending on the weather conditions existing during the blooming period and is not a dependable measure for prediciting yields.

A study of this nature is valuable in determining areas best suited for a crop that has a critical environmental requirement as does the field bean.

Table 1.--Correlation coefficients calculated between the per cent set of pods *vs*. temperature, per cent set of pods *vs*. relative humidity, and temperature *vs*. humidity for plants grown in the greenhouse in 1940

Per cent set of pods *vs*. maximum temperature on day blossoms were tagged	-0.3334
Per cent set of pods *vs*. average maximum temperature for two successive days	-0.3078
Per cent set of pods *vs*. minimum relative humidity on day blossoms were tagged	0.2175
Average maximum temperature for two successive days *vs*. minimum relative humidity for date blossoms were tagged	-0.5929*

*Significant at the 1 per cent level. Coefficients based on the per cent set of a total of 993 blossoms tagged for twenty-eight different days.

Table 2.--The effect of fertilizer, date of planting, and moisture levels on the yield of beans, greenhouse, 1940*

Treatment	Yield - Grams of beans from two jars					
	Low moisture level		Optimum moisture level		High moisture level	
Date of planting	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized
April 4, 1940	5.41	2.09	8.63	6.16	12.75	6.35
April 27, 1940	9.40	5.24	11.77	6.04	12.69	7.17
May 18, 1940	7.58	5.07	8.16	6.61	12.63	7.87
May 31, 1940	7.14	3.59	6.58	5.07	9.66	5.78
June 18, 1940	5.94	2.95	9.08	5.77	7.39	8.44
July 16, 1940	7.63	3.76	11.11	7.17	12.76	7.90
August 1, 1940	3.18	0.65	8.93	2.82	5.77	3.31

*Low, optimum, and high moisture levels refer to 300,500, and 750 cc. of water added per jar containing 4.5 kilograms of soil. Fertilizer applied at the rate of 600 pounds of 4-16-8 per acre.

Source	D.F.	Sums of squares	Mean square	Std. dev.
Total	83	226.67		
Within classes	42	42.08		
Dates	6	44.60	7.43*	
Moisture levels	2	48.02	24.01*	
Fertilizer	1	65.86	65.86*	
Dates x moisture levels	12	10.75	0.90	
Dates x fertilizers	6	5.39	0.90	
Moisture level x fertilizer	2	0.28	0.14	
Error	12	9.69	0.82	0.906

*Significant at the 1 per cent level.

Table 3.--Correlation coefficients and corresponding z values calculated between leaf area and yield of plants grown in the greenhouse in 1940

Treatment	No fertilizer		Fertilized*		Fertilized and no fertilizer	
	r**	z	r	z	r	z
Planted April 4	0.6460	0.7685	0.9210	1.5957	0.8924	1.4339
Planted April 16	0.6884	0.8450	0.8490	1.2527	0.9043	1.4954
Planted May 18	0.5357	0.5981	0.6440	0.7550	0.6281	0.7383
Planted May 31	0.6750	0.8163	0.6892	0.8465	0.7278	0.9241
Planted June 18	0.9018	1.4819	0.5378	0.6011	0.5871	0.6733
Planted July 16	0.8222	1.1637	0.7441	0.9597	0.8529	1.2670
Planted August 1	0.7353	0.9403	0.7669	1.0128	0.8478	1.2485
Low moisture level	0.5605	0.6335	0.6091	0.7075	0.7550	0.9846
Optimum moisture level	0.4906	0.5369	0.7428	0.9568	0.7646	1.0073
High moisture level	0.5342	0.5960	0.4618	0.4996	0.5834	0.6677
Total of all plants	0.6578	0.7890	0.4664	0.5055	0.7146	0.8966
Difference required for significance						
Planting dates		0.8051		0.8051		0.5181
Moisture levels		0.4762		0.4762		0.3146
Fertilized and unfertilized plants		0.2578		0.2578		

*600 pounds of 4-16-8 fertilizer per acre was mixed with the soil before placing in the jars.

**All correlation coefficients are significant at the 5 per cent level and at the 1 per cent level with the exception of "May 18, no fertilizer" and "June 18, fertilized".

Table 4.--Correlation coefficients and z values calculated between the per cent set of pods and temperature, Miller farm, 1940 and 1941

		1940	1941	1940 and 1941
Per cent set of pods *vs.* maximum temperature on day blossoms were tagged	r	-0.6107	-0.6576	-0.5962
	z	-0.7100	-0.7886	-0.6872
Per cent set of pods *vs.* average maximum temperature for two successive days	r	-0.6908	-0.6527	-0.6235
	z	-0.8495	-0.7800	-0.7307
Per cent set of pods *vs.* temperature expressed as area under curve at base 70° on day blossoms were tagged	r	-0.7228	-0.7503	-0.6095
	z	-0.9135	-0.9737	-0.7081
Per cent set of pods *vs.* temperature expressed as area under curve at base 60° on day blossoms were tagged	r	-0.7459	-0.6450	-0.7063
	z	-0.9638	-0.7668	-0.8798
Per cent set of pods *vs.* temperature expressed as average area under curve for two successive days at base 70°	r	-0.6569	-0.6585	-0.6659
	z	-0.7874	-0.7902	-0.8034
Per cent set of pods *vs.* temperature expressed as average area under curve for two successive days at base 60°	r	-0.7707	-0.5965	-0.6424
	z	-1.0221	-0.6877	-0.7623
Difference between z values required for significance		0.8104	0.7673	0.5070

All correlation coefficients are significant at the 1 per cent level.

Table 5.--Correlation coefficients and z values calculated between the per cent set of pods and relative humidity, Miller farm, 1940 and 1941

		1940	1941	1940 and 1941
Per cent set of pods *vs.* minimum relative humidity on day blossoms were tagged	r z	0.5126* 0.5662	0.4698* 0.5098	0.4653** 0.5042
Per cent set of pods *vs.* average minimum relative humidity for two successive days	r z	0.4302 0.4850	0.6255** 0.7340	0.4454** 0.4790
Per cent set of pods *vs.* relative humidity expressed as area under curve at base 50 per cent		-0.5316		
Difference between z values required for significance		0.8104	0.7673	0.5070

*Significant at the 5 per cent level.
**Significant at the 1 per cent level.

Table 6.--Correlation coefficients and z values calculated between maximum temperature and minimum relative humidity, Miller farm, 1940 and 1941

		1940	1941	1940 and 1941
Average maximum temperature for two successive days *vs.* minimum relative humidity for date blossoms were tagged	r z	-0.4421 -0.4417	-0.4421 -0.4747	-0.4664* -0.5055
Average maximum temperature for two successive days *vs.* average minimum relative humidity for two successive days	r z	-0.2563 -0.2621	-0.4403 -0.4725	-0.4234* -0.4518
*Difference in z values required for significance.				0.5070

Table 7.--Multiple and partial correlation coefficients calculated between per cent set of pods, maximum temperature, and minimum relative humidity, Miller farm, 1940 and 1941

Rx.yz*	0.6538
rxy.z	-0.5192
rxz.y	0.2523

*x refers to per cent set of pods, y to average maximum temperature for two successive days, and z refers to minimum relative humidity for date blossoms were tagged.

Table 8.--Predicting line calculated between per cent set of pods and maximum temperature, Miller farm, 1940 and 1941

Predicting equation	$y = -1.8x + 192$*
Standard error of prediction	3.82
Per cent error of mean	7.62

*x refers to the average maximum temperature for two successive days and y to the per cent set of pods.

Table 9.--Mean differences between daily maximum temperature and minimum relative humidity at the Miller and Horst farms in 1941

Location	Maximum temperature				Minimum relative humidity			
	July 14 - August 30		July 14 - August 17		July 18 - August 17		July 14 - August 17	
	Mean	Mean diff.	Mean	Mean diff.	Mean	Mean diff.	Mean	Mean diff.
Miller farm	80.43	3.79**	82.17	3.54**	29.86	2.46***	27.83	2.81**
Horst farm	76.64		78.63		32.32		31.37	

*The Horst farm, Akron, Michigan is located in the typical pea bean area and the Miller farm, Ovid, Michigan is located just outside of the most favorable bean growing area.
**Significant at the 1 per cent level.
***Significant at the 5 per cent level.

Table 10.--Correlation coefficients calculated between per cent set of pods and soil moisture, Miller farm, 1940 and 1941

	1940 and 1941
Per cent set of pods *vs*. per cent moisture in surface soil	0.3482*
Per cent set of pods *vs*. per cent moisture in subsoil	0.1913

*A value of 0.3976 is required for significance at the 5 per cent level.

Table 11.--The effect of fertilizer on the per cent set of pods, Miller farm, 1940 and 1941

	1940			1941			
	Fertilized	Unfertilized	Weighted* Mean		Fertilized	Unfertilized	Weighted* Mean
July 23	10.0	2.5	3.5	July 14	67.1	52.6	60.2
July 24	10.6	6.7	8.4	July 16	80.1	69.3	74.4
July 26	18.8	12.1	15.8	July 18	91.8	85.9	89.7
July 29	11.1	12.4	11.8	July 21	78.9	71.2	74.1
July 30	5.1	6.5	5.7	July 23	75.5	65.6	69.8
August 2	22.1	24.7	23.2	July 25	38.6	27.3	32.9
August 5	50.7	49.7	50.2	July 28	19.7	18.9	19.5
August 7	51.8	67.6	59.3	July 30	39.1	23.9	36.5
August 10	72.5	74.8	73.5	August 1	21.7	25.7	22.8
August 12	74.1	72.5	73.4	August 4	13.0	14.6	13.5
August 14	46.3	54.3	51.9	August 6	4.3	15.0	9.0
August 16	73.9	81.3	77.1	August 8	16.2	20.1	13.6
August 19	63.3	64.0	63.6	August 11	53.9	55.5	52.4
August 20	68.4	76.5	73.8	August 13	29.1	50.0	37.2
August 23	53.3	78.9	66.3	August 25	72.8	73.4	73.2
August 31	89.8	84.8	87.3	August 28	73.1	58.3	72.2
Sept. 3	94.0	92.3	93.1				

*Means weighted according to number of blossoms counted

	1940				1941		
Source	D.F.	SS	MS		D.F.	SS	MS
Total	33	30,817.24		Total	31	21,339.30	
Dates	16	30,190.56	1886.91**	Dates	15	20,496.60	1,366.44**
Fertilizer	1	61.70	61.70	Fertilizer	1	70.81	70.81
Error	16	565.18	35.51	Error	15	771.89	51.46

**Significant at the 1 per cent level. The per cent set of pods is based on 21,036 blossoms in 1940 and 14,508 blossoms in 1941, totaling 35,544 blossoms for the two years.

Table 12.--The effect of fertilizer and date of planting on the yield of beans, Miller farm, 1939

Planting date	Yield - bushels per acre*	
	Fertilized	Unfertilized
May 31	14.0	8.9
June 3	10.4	6.4
June 6	11.9	6.3
June 9	10.3	5.6
June 12	12.7	7.0

*Average of four replications. Fertilizer treatment, 500 pounds of 4-16-8 per acre.

Source	D.F.	SS	MS
Total	39	533.77	
Blocks	3	117.65	39.21
Dates	4	60.58	15.14**
Blocks x dates (a)	12	52.80	4.40
Fertilizer	1	248.56	248.56***
Fertilizer x dates	4	3.94	0.99
Error (b)	19	50.24	2.64

**Significant at 5 per cent level.
***Significant at 1 per cent level.

Table 13.--Means of yield, leaf areas, and weight of straw of individual bean plants, Miller farm, 1940 and 1941

Date Planted	Fertilized*			Unfertilized		
	Grams beans	Sq.in.leaf area	Grams straw	Grams beans	Sq.in.leaf area	Grams straw
1940						
June 8	68.5 ± 7.2	309.2 ± 27.2	47.9 ± 4.4	63.4 ± 6.1	254.7 ± 19.7	43.3 ± 4.3
June 11	51.5 ± 4.2	271.0 ± 17.9	39.5 ± 3.1	53.2 ± 4.4	199.4 ± 13.6	35.9 ± 3.0
June 14	45.1 ± 5.1	248.3 ± 15.3	36.1 ± 4.0	27.0 ± 2.6	165.2 ± 12.9	23.2 ± 2.5
June 17	31.3 ± 2.9	201.2 ± 10.2	27.3 ± 2.3	34.3 ± 4.0	154.9 ± 10.7	29.0 ± 1.6
June 25	21.2 ± 3.9	474.4 ± 44.9	32.7 ± 3.3	17.5 ± 1.8	406.2 ± 18.3	26.7 ± 2.4
1941						
June 3	45.3 ± 5.9	403.6 ± 26.4	64.3 ± 3.2	37.8 ± 3.1	237.6 ± 21.3	35.6 ± 3.7
June 9	39.5 ± 1.6	389.4 ± 18.1	38.6 ± 1.9	26.1 ± 1.5	225.5 ± 15.0	21.3 ± 1.3
June 16	38.5 ± 1.5	380.0 ± 24.6	34.5 ± 1.0	28.7 ± 1.6	216.3 ± 9.6	22.6 ± 1.5
June 24	34.3 ± 1.6	335.7 ± 16.9	30.5 ± 1.0	26.7 ± 1.1	193.5 ± 10.3	21.2 ± 1.3

*Bean plants were fertilized with 500 pounds of 4-16-8 fertilizer per acre.

**The data are based on a total of 158 leaf areas and 159 straw weights in 1940 and 162 leaf areas and 169 straw weights in 1941.

Table 14.--Mean differences of yield, leaf area, and weight of straw between fertilized and unfertilized bean plants, Miller farm, 1940 and 1941

Date Planted	Grams beans	Sq. in. leaf area	Grams straw
	1940		
June 8	5.1 ± 9.4	54.5 ± 33.6	4.6 ± 6.2
June 11	-1.7 ± 6.1	71.6 ± 22.5*	3.6 ± 4.3
June 14	18.1 ± 5.7*	83.1 ± 20.0*	12.9 ± 4.7*
June 17	-3.0 ± 4.9	46.3 ± 14.8*	-1.7 ± 2.8
June 25	3.7 ± 4.3	68.2 ± 48.5	6.0 ± 4.1
	1941		
June 3	7.5 ± 6.7	166.0 ± 33.9**	28.7 ± 4.9**
June 9	13.4 ± 2.2**	163.9 ± 23.5**	17.3 ± 2.3**
June 16	9.8 ± 2.2**	163.7 ± 26.4**	11.9 ± 1.8**
June 24	7.6 ± 1.9**	142.2 ± 19.8**	9.3 ± 1.6**

*Significant at 5 per cent level.
**Significant at 1 per cent level.

Table 15.--Correlation coefficients calculated between leaf area *vs.* yield and weight of straw *vs.* yield, Miller farm, 1940

Date planted	Dates % set of pods was determined	Fertilized* Leaf area *vs.* yield	Fertilized* Weight of straw *vs.* yield
June 8	July 16 - Aug. 14	0.5552**	0.9403***
June 11	July 22 - Aug. 14	0.3726	0.7859***
June 14	July 30 - Aug. 16	-0.7366**	0.8989***
June 17	July 30 - Aug. 20	-0.2746	0.9121***
June 25	Aug. 16 - Aug. 23	0.4500	0.6703***
		Unfertilized	
June 8	July 23 - Aug. 14	0.6044**	0.9674***
June 11	July 24 - Aug. 19	0.3853	0.8693***
June 14	July 29 - Aug. 12	0.3127	0.7867***
June 17	July 30 - Aug. 20	0.2922	0.6733***
June 25	July 16 - Aug. 23	0.2800	0.6474***

*Bean plants were fertilized at the rate of 500 pounds of 4-16-8 per acre.
**Significant at the 5 per cent level.
***Significant at the 1 per cent level.

Table 16.--Correlation coefficients calculated between leaf area *vs.* yield and weight of straw *vs.* yield, Miller farm, 1941

Date planted	Dates % set of pods was determined	Fertilized* Leaf area *vs.* yield	Weight of straw *vs.* yield
June 3	July 14 - July 28	0.5381	0.0579
June 9	July 23 - Aug. 13	0.5015**	0.1732
June 16	July 30 - Aug. 11	0.5488**	0.5474**
June 24	Aug. 22 - Aug. 28	0.1539	0.6169***
		Unfertilized	
June 3	July 14 - July 30	0.5843	0.3956
June 9	July 30 - Aug. 13	0.4526**	0.8850***
June 16	Aug. 6 - Aug. 11	0.2026	0.6077***
June 24	Aug. 22 - Aug. 28	0.4735**	0.7969***

*Bean plants were fertilized at the rate of 500 pounds of 4-16-8 per acre.
**Significant at the 5 per cent level.
***Significant at the 1 per cent level.

Figure 1. The difference in the number of pods between the two groups of plants are the result of changing weather conditions at the time of blooming. The plants on the left were planted one week earlier than the plants on the right and blossomed during a more favorable period for setting pods than those on the right. The plants on the right are practically devoid of pods.

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