A STUDY OF CERTAIN FACTORS AFFECTING THE SET OF FRUIT IN HENDERSON BUSH LIMA BEAN.

BY

Howard B. Cordner.

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789 East Eisenhower Parkway
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A STUDY OF CERTAIN FACTORS AFFECTING THE SET OF FRUIT IN HENDERSON BUSH LIMA BEAN.

INTRODUCTION

The excessive dropping of Lima bean blossoms is of common occurrence in many sections of the United States. This has caused considerable apprehension among the growers in commercial producing sections and frequently crop failures have been attributed to severe blossom drop and failure of fruit set. In spite of the economic importance of this problem little or no data have been published indicating the extent of the drop, its relationship to crop failures, or the factors which might be associated with its occurrence. This dearth of information has made it impossible to satisfactorily answer numerous inquiries relative to the set of fruit in Lima beans coming in from growers in Maryland and other states. There is a need for definite information relative to the factor or factors responsible for bringing about the dropping of flowers and fruits to serve as a basis for devising some practical remedy for the apparently unfruitful condition in Lima beans.

Numerous investigations with other plants have disclosed a great number of factors which at times are active causes of unfruitfulness. In general these factors can be divided into two classes –– external and internal. Of the external factors, unfavorable atmospheric conditions such as a high temperature and low humidity have frequently been found associated with the abscission of the reproductive structures of plants. The destructive influence of these factors is usually intensified by inadequate soil moisture. In regard to the factors operating within the plant, unfruitfulness might arise from improper mineral nutrition or, perhaps from unequal relationship between the reproductive and vegetative functions. Other possibilities are: the absence of pollination, lack of fertilization, and abortion of embryos.

Preliminary observations indicated that both external and internal factors were active in bringing about the dropping of blossoms in Lima beans, and consequently both were considered in this investigation. Data were taken over a four year period -- 1928 to 1931. For convenience the material is presented under several heads as follows: (A) Growth, flowering, and fruiting habit -- presented in an introductory manner to provide the reader with a knowledge of the mode of development of the plant and the way in which flowering and fruiting occur. This manner of presentation was considered desirable because the shedding of a large proportion of the blossoms normally occurs and fruitfulness is intimately related to the development of the plant. The presentation of the subsequent data is centered about this important point. (B) Extent, nature, and daily rate of abscission of reproductive parts. (C) The influence of temperature, relative humidity and precipitation on growth, yield, and the set of fruits in relation to time of planting and flowering. (D) Behavior of the plant as affected by nitrogen and phosphorus. (E) Chemical composition of the plant. (F) Relation between set of fruit on the raceme and the number of seeds developed in the pod. (G) Histological studies of stamens and pistils in relation to the drop.

REVIEW OF LITERATURE

The causes of unfruitfulness in plants are so numerous and literature on the subject so abundant that a complete review of literature is beyond the province of this paper. Reference is made to the comprehensive discussion of the subject by Gardner, Bradford, and Hooker (7), and herein only those investigations most pertinent to the study at hand will be considered.

Certain relationships have been established between the vegetative and reproductive functions in plants. In general it has been demonstrated that the set and development of fruits exerts a retarding influence on vegetative growth and may also condition further reproductive activity. Mattirolo (16) maintained plants of Vicia faba in a vegetative state, long past their normal vegetative life by continued defruiting. Such defruited plants were abnormally vegetative and the nitrogen content of the nodules remained at an unusually high level. Bushnell (4) and Rosa (22) observed a distinct periodicity in the setting of fruit in certain Cucurbitaceae.. Mason (17) found that vegetative growth ceased with the set of fruits in Sea Island cotton. Abscission of flowers become more pronounced with the cessation of growth and both were attributed to a correlation factor diverting elaborated foods to the fruits set on the lower branches of the plant.

Murneek (18) described a case of intermittent sterility in the spider flower as a direct effect of the set of fruit. An abundant supply of nitrogen favored hermaphroditism and fruit set. Hermaphroditism continued indefinitely when fruit set was prevented by defloration. Murneek (19) found that the developing tomato fruits have a high nitrogen requirement which may be satisfied at times at a sacrifice of vegetative growth and further fruiting. According to Smith (24) the abscission of blossoms of eggplant occurs principally in multi-flowered inflorescences.

The studies cited above suggest that fruit development limits vegetative growth and further fruiting somewhat inversely to the supply of nitrogen. Many other materials are required for vegetative and reproductive development and therefore the supply of nutrients other than nitrogen may limit the fruitfulness of plants. Kraybill (10) produced different degrees of fruitfulness in tomato plants by varying the level of phosphorus and potassium in the nutrient supply. Hepler (8) and Hepler and Kraybill (9) found the set of tomato blossoms to be increased by applications of acid phosphate. Kraybill and Smith (11) and MacGillivray (14) report a reduction in the fruitfulness of tomatoes grown in sand in the absence of phosphorus. The chemical composition of these phosphorus deficient plants compared to normal plants was characterized by a high soluble and total carbohydrate content, high soluble and total nitrogen and low insoluble nitrogen content.

Excessive dropping of blossoms and unfruitfulness in plants have frequently been associated with unfavorable climatic conditions such as high temperature and low humidity. Radspinner (21) and Smith (23) have shown that high atmospheric temperature, especially in connection with low humidity and low soil moisture, reduce the set of tomato blossoms. Mason (17) failed to find any direct relation between climatic factors and abscission of the blossoms of cotton. The drop increased associated with days with little direct solar radiation was attributed to retardation in the assimulative activity of leaves. Dutt (6) also studying cotton observed that the water content of these plants varied with the available moisture in the soil. The formation of abscission layers was found to be associated with a reduction in the water content of the pedicle.

The relation of temperature to many of the vital processes within the plant has been clearly demonstrated in the past. Growth is the product of many of these processes and the formal effects of temperature on growth are very evident. Clausen (3) found a temperature coefficient of about 2.5(for temperatures ranging from 0 - 20°C) for the rate of respiration in lupine seedlings. Matthaei (15) gives a temperature coefficient of 2.1 for the rate of photosynthetic activity in leave of cherry laurel in a temperature range of 9 - 19°C. Price (20) found the time required for the opening of buds, of certain deciduous plants, to be reduced by about one-half by a 10°(C) rise in temperature. Lehenbauer reports a temperature coefficient of 1.88 to 2.40 for twelve hour growth period in maize seedlings developing within a temperature range of 20 - 30°C.

Various methods of evaluating the influence of temperature on the growth rate have been suggested: (1) the remainder indices or heat summations, (2) the exponential indices proposed by Livingston - Livingston (11) and (3) the physiological summation indices suggested by Livingston (12). Appleman and Eaton (1) have shown that the rate of ripening in sweet corn is inversely proportioned to the exponential indices. Boswell (2) found that the blossoming and harvest stages of development in peas were attained with the reception of a fairly constant amount of heat as determined by the remainder indices based on 40°F.

GROWTH, FLOWERING, AND FRUITING HABIT

In the preliminary studies conducted in the years 1928 and 1929 certain observations were made and data taken relative to the vegetative development, flowering and fruiting in Lima beans in order to secure a better understanding of the plant as an aid in pursuing the study of blossom drop. These data and observations are briefly summarized here as they relate to the dropping of the reproductive structures.

Growth of Main Axis and Laterals

Following germination and the emergence of the seedling the main axis elongates beyond the unfolded primary leaves. Nodes are established at intervals on the axis with the origin and development of leaves. (The phyllotaxy varying with varieties, for example, the leaves of Fordhook are usually inserted in an opposite manner, those of Henderson Bush Lima being alternate. Some variations may occur in either case) Possibly a week later the nodes thus established may produce primary laterals which appear in the axils of the leaves beginning with the basal primary leaves.

The development of these primary laterals is similar to that of the main axis and therefore secondary laterals may appear in the axillary position on these. In general the extent of the development of the main axis and especially that of the laterals, depend upon such factors as the moisture and nutrient supply in the soil and the food balance in the plant. At times the main stem may be limited to a few nodes with still fewer primary laterals. Under conditions favoring a more luxuriant development, a longer main stem is produced, with numerous primary and secondary laterals. Regardless of the limitations imposed upon the vegetative development of these plants by the environment the potentiality for renewal of growth is maintained. Thus latent axillary buds along with extra axillary buds initiated on either side and at the base of all laterals, may become active and develop into branches when favorable environmental conditions occur. The moisture supply and fruit development are two factors most frequently determining vegetative growth. Therefore bean plants growing under rather droughty conditions will grow but slowly and be small in stature, while vegetative development will cease entirely with the set of a few fruits. The increased moisture supply following a rain induces new vegetative growth and subsequent flowering and fruiting in these plants already carrying a partly mature crop of pods. Such a condition is very troublesome in a crop intended for the cannery since the presence of the less mature fruits of the late set may result in faulty judgment of proper time to harvest. A late harvest usually results in a high percentage of white beans.

The resumption of vegetative growth following the maturation of the fruit in bush Limas is another example of the development of the dormant extra-axillary buds, probably in response to an accumulation of food materials which formerly were monopolized by the fruit. This cycle development is quite marked in the Henderson variety which may set a great number of fruits as a second crop following the maturation of a first.

Raceme Production

A vegetative period of twenty-five to forty days follows the emergence of the seedlings after which determinate racemes appear, these prohibiting further extension of laterals and the main stem of the plant on which they are borne. Axillary racemes arise at about the same time from buds on the main stem and on laterals branches. Figure I shows a main stem of Hendersons Bush with laterals and leaves removed. Two indeterminate or axillary racemes are born near the base of this stem which is also terminated by a determinate raceme. Fruits are born in the leaf axils at the two intervening nodes in the absence of racemes. The branches distant from the lower nodes produce racemes in a manner similar to the main stem, although they usually exhibit fewer fruitful nodes and hence fewer indeterminate racemes.

It is evident that within limits the relative number of indeterminate and determinate racemes depends upon the

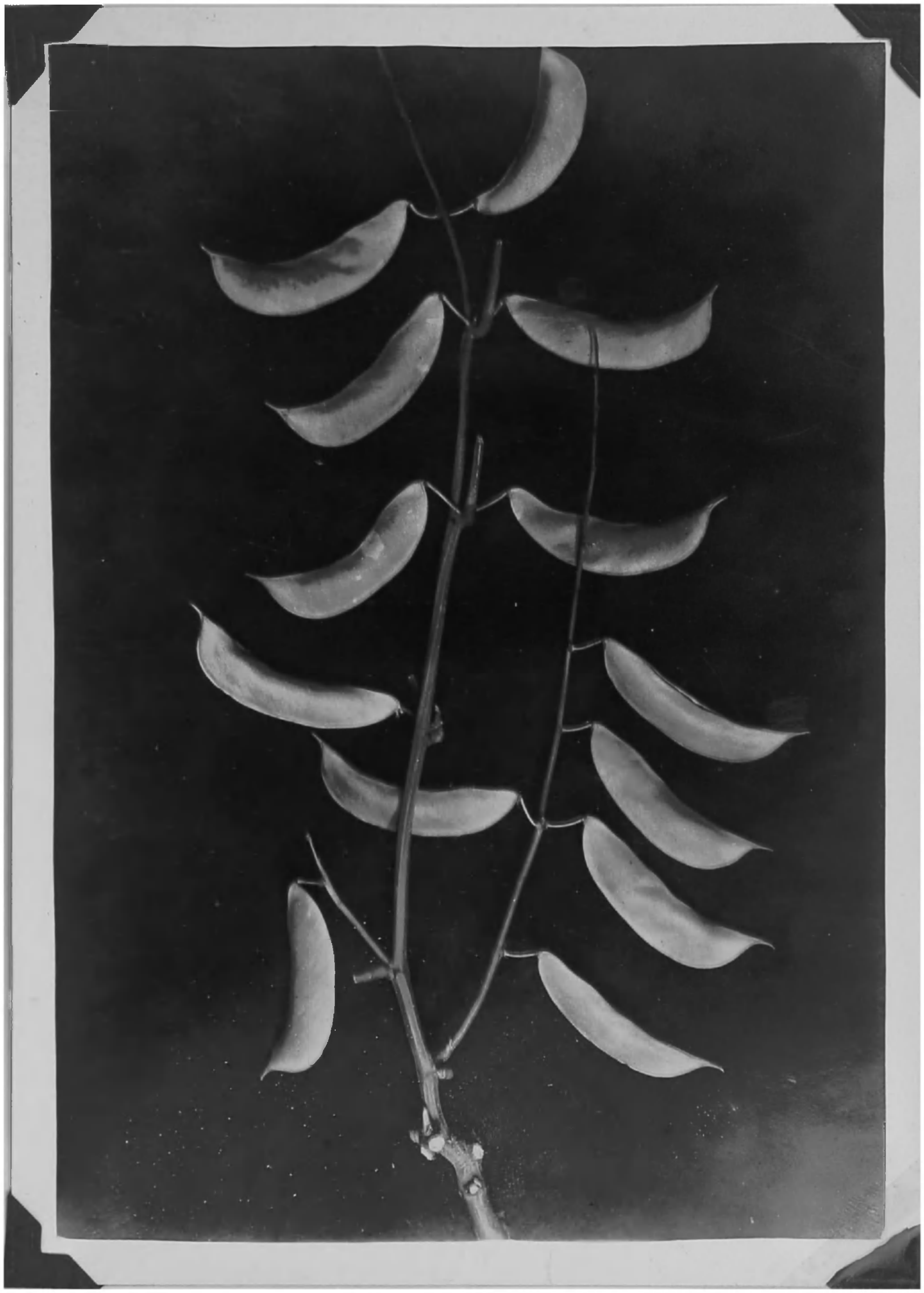

Figure I -- Main stem of a Henderson Bush plant illustrating the manner in which the fruits are borne.

vegetative vigor of the plant. Extremely vegetative growth produces many long branches usually with numerous indeterminate racemes, while plants of only moderate or poor vigor produce fewer and shorter branches with the most of the racemes of the terminal or determinate type. (Table I)

TABLE I — RELATIVE NUMBER OF DETERMINATE AND INDETERMINATE RACEMES IN RELATION TO SIZE OF THE PLANT.

Date Taken: (1930)	Date Planted.			
	May 17	June 7	June 14	June 28
Av. Weight of Plant (grams)-	146.0	113.7	87.4	46.1
Percent of Total Racemes:				
1. Determinate, - - - - -	36.59	45.40	58.92	46.11
2. Indeterminate, - - - -	63.41	54.60	41.08	53.89

The plantings made in 1930, a very dry season, showed a marked reduction in vegetative vigor as the date of seeding was delayed due to the decline in available moisture. Accompanying this decrease in vigor and reduction in the size of the plant there was a tendency for the percentage of indeterminate racemes to diminish. The planting of June 28 proved to be an exception to the trend, probably because belated rains occurred during the latter part of the life of these plants and late racemes were pushed out from the heretofore latent nodal buds, thereby increasing the number of indeterminate racemes.

Flowering and Fruiting Habit in Relation to Blossom Drop.

The inflorescense of the Lima bean is of the racemose type hence the central axis may elongate indefinitely since the growth is not terminated by a flower. Likewise development of the growing primordia at each node on the peduncle is not limited by morphological factors. A great number of buds or flowers may be produced at each node and spur-like out-growths may be produced, although normally development is definitely limited because of the set of fruit. At the time blossoming begins at a node no perceptible outgrowth is present. The node at this time possesses two open flowers separated by a cluster of buds in various stages of development.

Blossoming Sequences. No direct data were taken relative to the daily occurrence of open flowers on the racemes. However observations showed that blossoming begins at the basal node and progresses regularly upward. The rate at which this flowering wave ascends can be appreciated from other data taken on the drop rate. In this study five determinate racemes on each of sixty plants were tagged on July 1, 1929, as flowering was starting at the basal node. These racemes were visited daily and the drop of buds, flower, or immature fruits recorded with reference to the node at which abscissions occurred. Thus since the flower stage of development is relatively short (2 to 3 days) the sequence of flowering would conform quite closely to the sequence of dropping of flowers. Again since about ninety per cent of the flowers dropped a fairly definite trend is established.

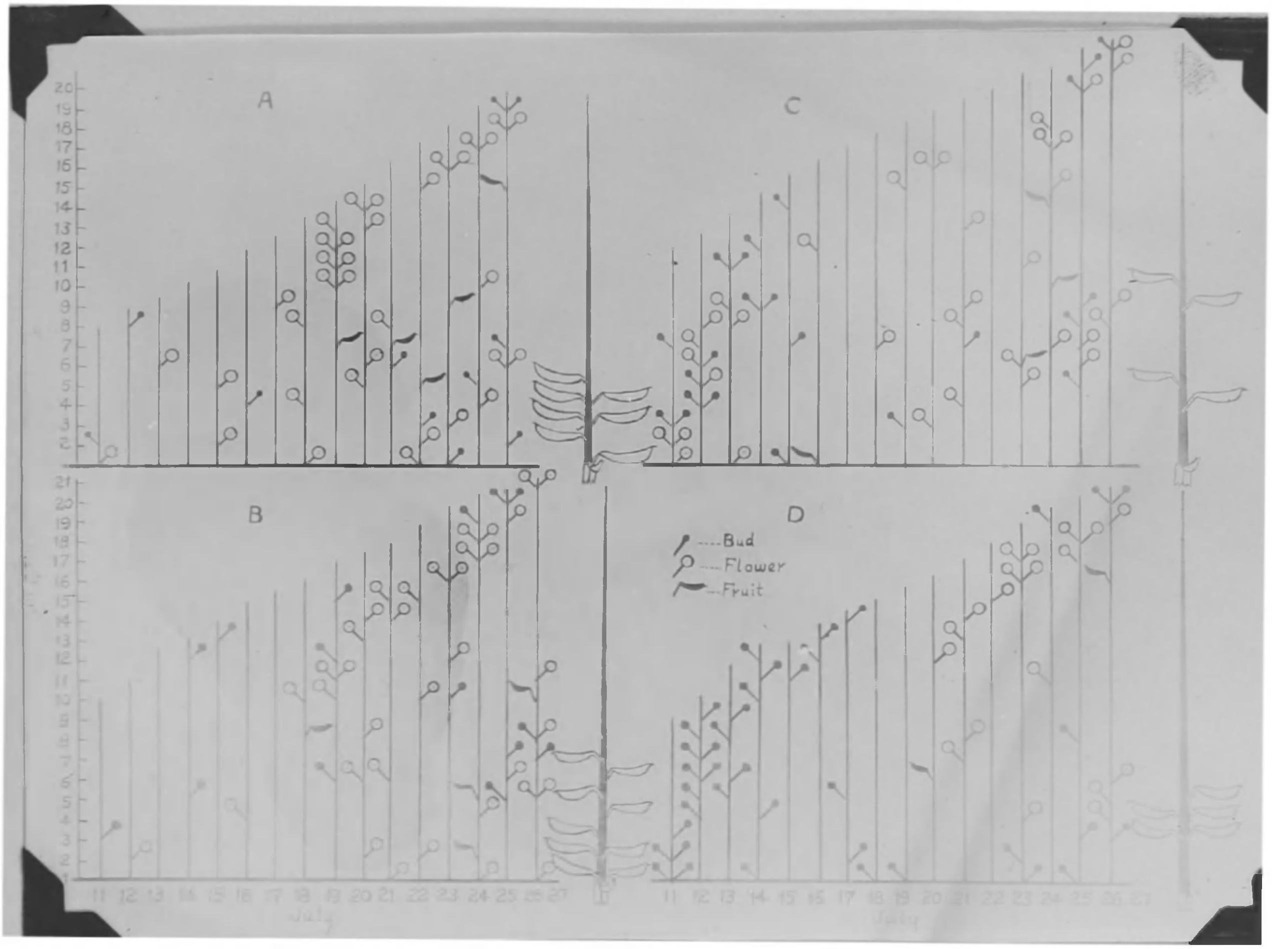

Figure II -- The drop history of four racemes illustrating the drop of buds, flowers, and immature fruits according to node of the raceme and the time of the occurrence of abscission. The final set for each raceme is represented at the right.

Figure II. illustrates the drop record and final set of four different racemes. It is evident that a distinct wave of flowering progresses up the raceme at a rate of about one node per day. In addition to the first series of blossoms a second and possibly a third cycle may follow. These are less distinct than the first and seldom reach the terminal nodes of the raceme, probably because of the rapid decline in vigor in that section of the peduncle as flowering progresses and fruits are set below.

The sequence of flowering doubtless is more regular than that of the flower drop since flowers of different ages may drop on the same day and also because there are some flowers which set. Again a great number of flower buds drop before opening. Thus the sequence of blossoming and also of blossom abscission are affected by the dropping of buds.

Fruit Set With Respect to Position on the Raceme.

The final set of fruit on the racemes represented in Figure II is with some exceptions confined largely to the basal nodes of the peduncle. This seemed to be characteristic of the three-hundred racemes used in the blossom drop study. Figure III (A) shows the percentage of the total number of fruits produced on the racemes that was set at each node. In spite of the fact that the racemes possessed as an average 18.7 nodes all the fruit was confined to the basal

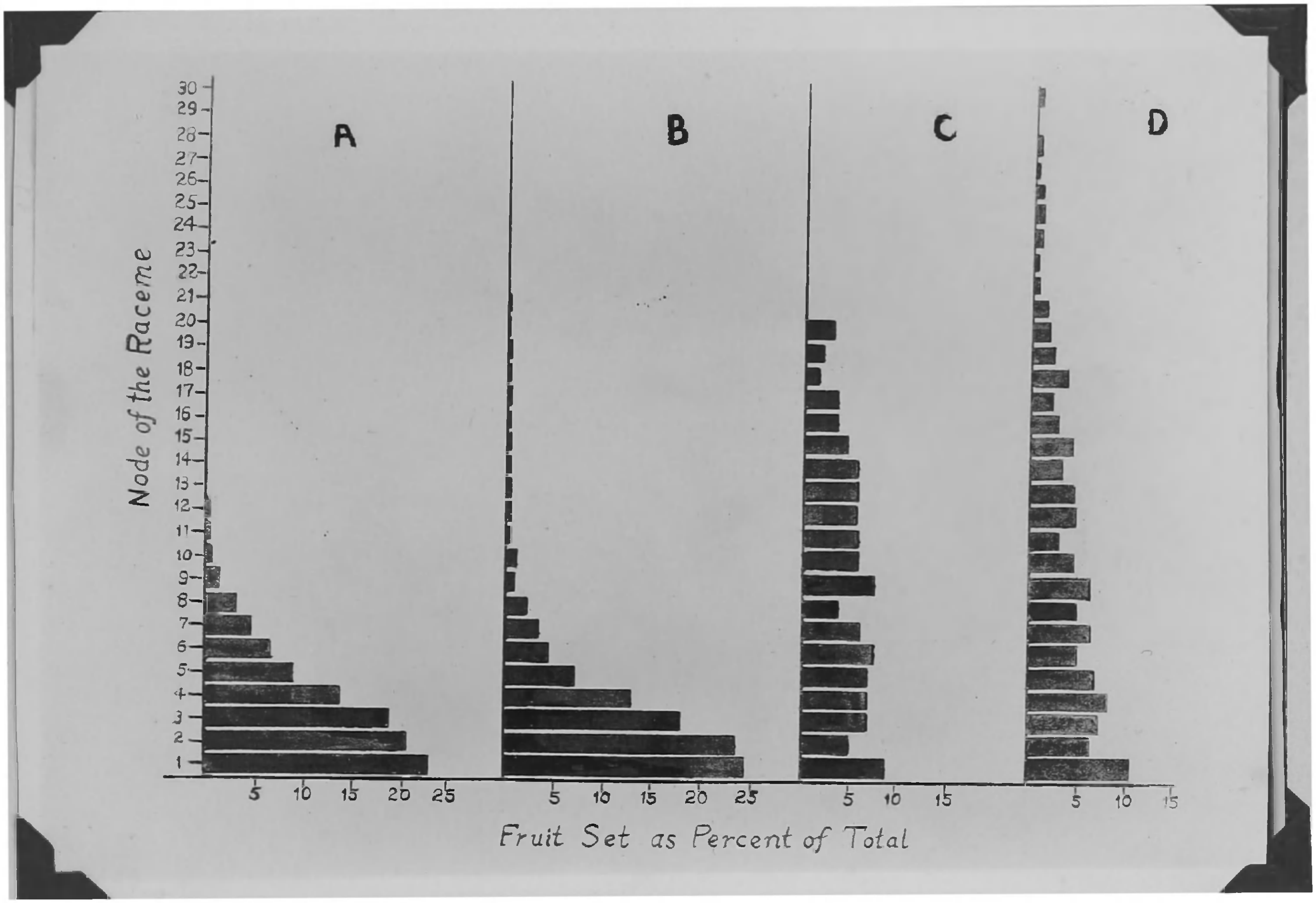

Figure III — The set of fruit according to nodes of the raceme: A, set on racemes in the field, 1929; B, prompt set and C, D, delayed set under greenhouse conditions.

twelve, with over twenty percent set on the first node. This appears to be the normal course of events when flowering occurs under conditions favoring fruit set. On the other hand if flowering is initiated at the base of the raceme under unfavorable conditions, fruit set might be delayed for a few days. Meanwhile the flowering wave is ascending the raceme and may pass several nodes before setting occurs. Referring again to Figure II, C and D, represent such a condition as just described. In C the drop of both buds and flowers was especially severe on the lower nodes and the set of fruit was displaced toward the terminal of the raceme.

Another case of delayed set was recorded in a group of plants grown in the greenhouse in 1929. Seeded in January, the plants initiated racemes in February but on account of unfavorable conditions, probably short days, buds continually abscissed so that no flowers developed. The racemes continued to elongate and buds were produced and dropped until finally about March 20 flowering occurred and a limited number of fruit were set. These fruits apparently monopolized available foods for a time since flowering ceased until May 17. On that date flowering was resumed on the old racemes and at the same time the plants showed new laterals bearing racemes which also flowered and set fruit promptly. Figure III (B) represents the set of fruit on these new racemes, (C) the first set (March 20) on the old racemes and (D) the second set (May 17) on these same old racemes. Thus, as illustrated by this extreme case of delayed set, it is apparent that the longer fruit setting is delayed the more is the tendency for the fruit to be born out further toward the end of the raceme.

From this discussion, based upon three-hundred racemes produced under field conditions, it is apparent that normally the set of fruit is confined to the lower nodes with a large number of the terminal nodes remaining totally barren. It might be reasoned that barrenness in the terminal part of the raceme is directly a result of the set and development of fruits on the basal nodes. Again, in cases where the set is temporarily delayed by some unfavorable internal or external factor, the fruit will be found distributed further up toward the terminal of the peduncle.

Defloration in Relation to Position of Fruit Set. In order to determine if the presence of fruit at the base of the raceme were responsible for the unfruitfulness of the more terminal nodes, a systematic defloration of a number of racemes was carried out. The blossoms were clipped off daily just prior to pollination in order to avoid any possible stimulus which might arise as a result of gametic union. Murneek (19). In this study racemes were deflorated entirely except at four nodes as follows: (1) flowers on the four nodes at the base of the peduncle were undisturbed, the remainder clipped off, (2) four nodes were left untreated in an intermediate position between nodes six and twelve, and (3) four nodes were left untreated near the terminal.

In order to obtain racemes that were flowering simultaneously in the three desired regions, thereby eliminating weather differences as affecting fruit setting, it was

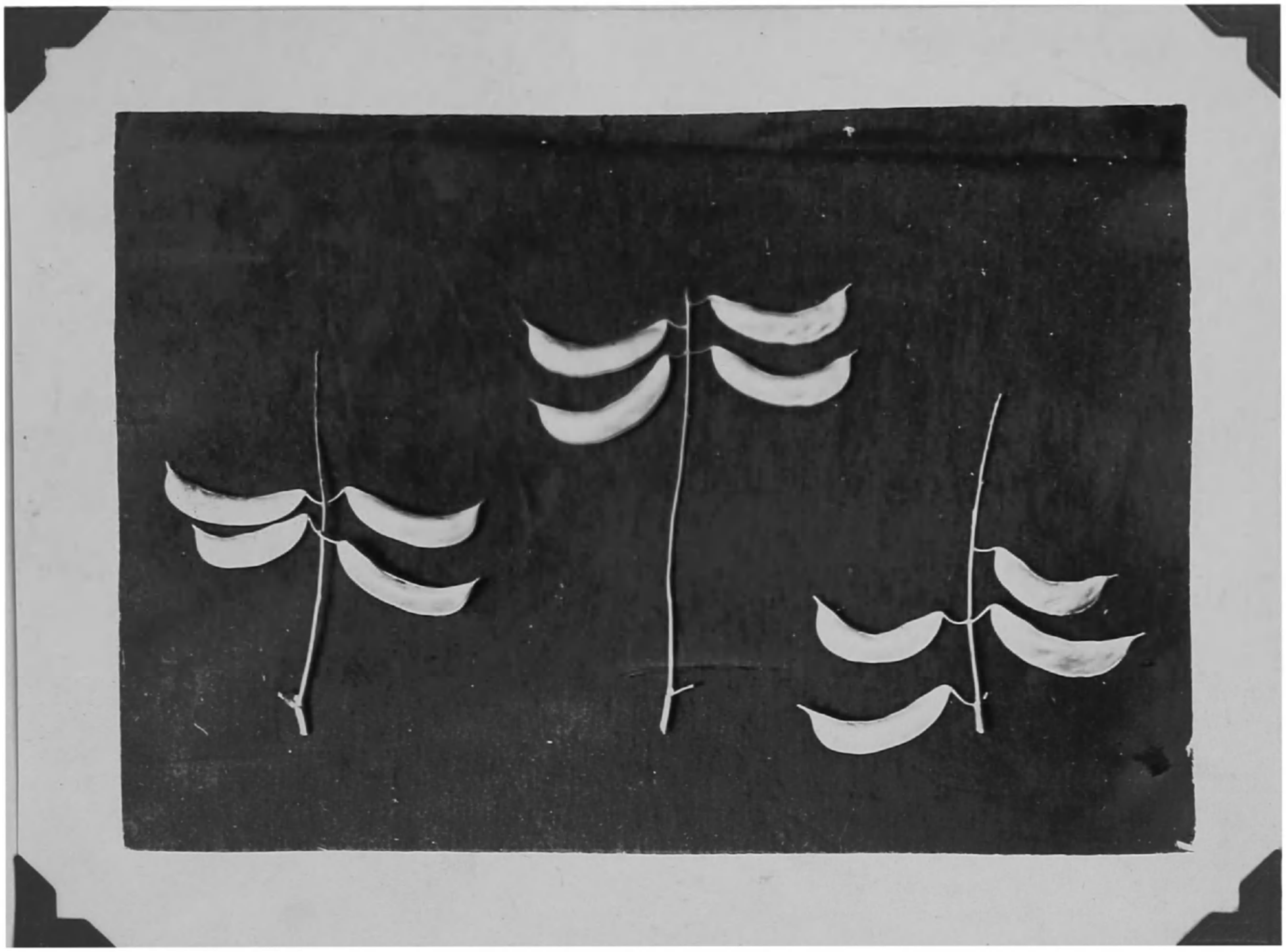

Figure IV -- Fruit setting can be induced at any region on the peduncle if other regions are deflorated.

necessary to work with plants from three different planting dates. The defloration was performed so that the blossoms allowed to remain were on plants and racemes of similar condition with reference to vegetative development, and no fruits had been allowed to set previously. Thus terminal, intermediate, and basal sets were secured on plants seeded May 24, May 31, and June 14 respectively. Figure IV illustrates the position in which the fruit set on the racemes and Table II presents a summary of the results.

TABLE II -- THE SET OF FRUITS ON DEFLORATED RACEMES

Data Secured (1929)	Position of Undeflorated Nodes.		
	Base	Middle	Terminal
Number of Racemes Treated - - - -	682	609	542
Average fruits set per raceme:			
1. Fruitful racemes, - - - -	2.43	2.30	1.72
2. Based on all racemes, - - -	1.88	1.34	0.78
Unfruitful racemes as percent of total, - - - - - - - - - - - - - -	22.58	41.88	54.68

It is evident that the set was greatest for those racemes which were permitted to fruit at the base. However, many fruits did set and develop at the terminal position and there is no doubt that this was far greater than it would have been had the racemes flowered under normal conditions in the absence of defloration. In fact as already has been shown in the case of the set of those racemes represented in Figure III (A) no fruits were set above the twelvth node, in spite of the fact that this group of racemes were of the same age and flowered concurrently with that group of the defloration study.

The reduction in the set at the terminal position, as compared with the basal position of the racemes, is possibly partly a result of the devitalizing influence of continued flower bud production, and probably more largely the result of the unfavorable position on the raceme with reference to availability of food supply. The terminal portion of the raceme is spindling and weak. This is further substantiated by the setting of fruits on the basal nodes in the second cycle of flowering. The study at least demonstrates that fruit will be set and matured at the terminal of the peduncles in the absence of fruit on the basal nodes, and it is strongly suggested that the barren terminals so common under natural conditions are a result of a physiological drop induced by the lack of requisite materials.

Fruit Set According to Position on the Plant. In the discussion of raceme production it was indicated that the fruit was borne on the plant in three ways: On determinate racemes, indeterminate racemes, and at the nodes of the stem in the absence of racemes. Furthermore it was shown that the relative number of determinate and indeterminate racemes varies with the size of the plant. It would be of interest to consider these positions to determine which is most favorable for set of fruit, and just how much each contribute to the total yield of the plant. Table III presents data taken from the same plants represented in Table I.

TABLE III — A COMPARISON OF DETERMINATE AND INDETERMINATE RACEME WITH RESPECT TO FRUIT SET.

Data Secured.	Date Planted (1930)			
	May 17	June 7	June 14	June 28
Number of plants measured - -	163	165	180	176
Average weight of plants (gms)	146.0	113.0	87.4	49.6
Fruit set as percent of total:				
1. On determinate racemes	66.61	71.10	74.85	86.88
2. On indeterminate racemes	21.60	20.93	20.04	11.32
3. Without racemes, - - -	11.71	7.97	5.10	1.81
Average fruits per raceme:				
1. Determinate, - - - - - -	3.61	2.40	2.46	2.32
2. Indeterminate, - - - -	2.44	1.87	1.81	1.33
Percent unfruitful racemes:				
1. Determinate, - - - - - -	12.61	8.60	2.85	4.31
2. Indeterminate, - - - -	76.06	71.26	52.50	81.39

It is evident that the majority of the fruits are born in a determinate position in spite of the greater number of indeterminate racemes. This is accounted for by both increased set per raceme and by a higher percentage of number of fruitful racemes. Evidently the determinate position is most favorable for fruit set. The unfruitfulness in indeterminate racemes is probably a result of several factors. Since many of them are produced under the more or less crowded conditions in the interior of the plant, the leaves with which they are immediately associated may have limited opportunities for carbohydrate synthesis. A greater possibility is that some of these indeterminate racemes may have been formed late, after the vegetative vigor of the plant had declined and these would likely be low in vigor and reduced in size. However it should not be concluded that all indeterminate racemes are less fruitful than determinate ones since some notable exceptions are found. Frequently racemes are developed near the base of the main stem subtended by a strong leaf which, in the absence of laterals at that particular node, may equal or even exceed the productivity of the determinate racemes of that plant. (See Figure I).

THE EXTENT, NATURE, AND DAILY TREND OF THE DROP

The influence of such environmental factors as temperature and humidity on the dropping of blossoms in several plants have been shown by correlation of the daily drop rate with these environmental factors. The following study was carried out with Henderson Bush Lima in order that such relationships might be studied.

At first sight it appeared easy to secure reliable data relative to the daily trend of the drop which would be correlated with the external environmental factors. Thus it was decided to record the daily drop throughout the blossoming life of a uniform group of racemes. Three-hundred determinate racemes of the same age representing sixty plants were selected and the daily drop of buds, flowers, and fruits recorded. After the data were summarized it indicated that such a method of attack had serious limitations in as much as a characteristic trend through the life of the raceme seemed to be established irrespective of weather. Apparently certain internal conditions resulting from the set of fruit and the gradual senescing of the raceme were instrumental in bringing about such a trend.

It might be agreed that data more comparable with external factors would be secured by using many series of racemes coming into blooming at intervals of a day or two in order to eliminate the influence of internal factors.

This is probably true but such series of racemes could not be secured on the same plants since it is likely that the later series would comprise the later formed less fruitful racemes. Thus it would be necessary to make seedings at frequent intervals in order to secure comparable racemes. This would entail a prohibitive amount of labor and because of variations in rate of germination and growth of plants resulting from different seedings, it would not be wholly satisfactory. Because of the practical impossibility of carrying out the more elaborate plan, a study of the daily drop throughout the life of one series of racemes was all that could be done. Although not the ideal way to attack this point, the present study shows some interesting and valuable results.

The racemes used in this study were determinate on the main stem and primary laterals, well distributed on the plant and apparently flowering for the first time on July 10th, when they were tagged. Daily examinations were made and the drop recorded according to the node of the raceme and the stage of development at which abscission occurred. The drops were classified as buds, flowers, and fruits, (See Figure V) representing the pre-pollination, pollination to petal fall, and after petal fall stages of development, respectively.

In securing the data, potential drops (those with abscission layer formed) were identified by a general yellowing in the case of buds, a yellowing of the pedicle

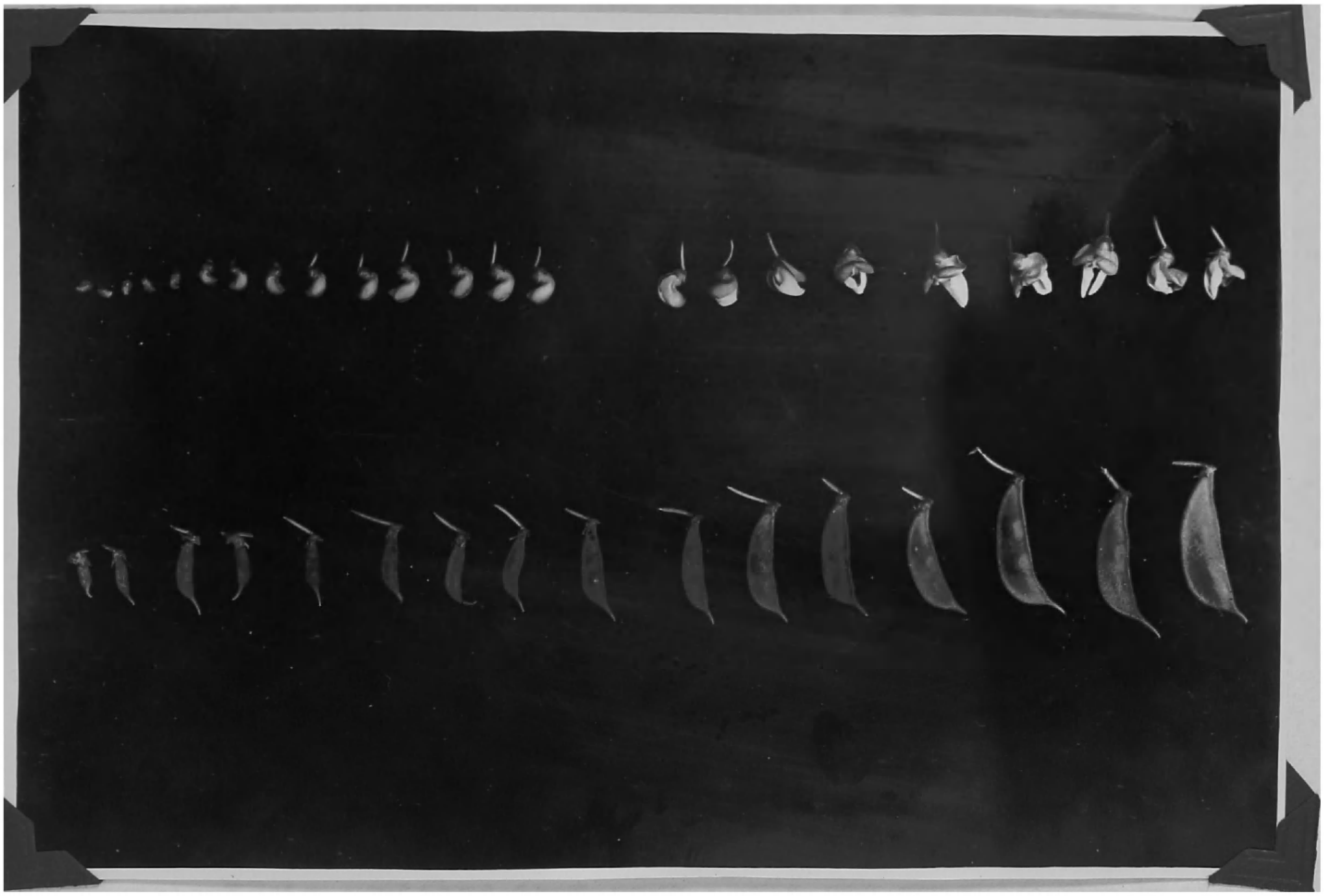

Figure V -- Illustrating buds, flowers, and fruits as classified in taking daily drop records: Buds, upper left; flower upper right, and immature fruits below.

in the case of flowers and young fruits. These were removed by means of a pair of narrow pointed forceps without injuring the other reproductive bodies. In some cases complete separation from the raceme had occurred and such drops were identified by reference to the past record of the raceme and the position of the node in question with respect to the flowering sequence. For example, normally two flowers open the same day at a given node. If only one flower were present when the raceme was examined and its absence were not accounted for by a previous bud drop it was concluded that the flower had fallen since the previous examination. The nature of the abscission scar was helpful in confirming such conclusions. The reliability of the date was increased by a tendency for flowers to separate first at the flower-pedicel junction leaving the pedicel adhering to the peduncle. In the case of buds there was less chance of their becoming lost since on account of lack of weight and the contact with other buds they more consistently adhered after the formation of the abscission layer.

It is admitted that some error was unavoidable in such methods of recording the drop but it is not likely that it was sufficient to seriously affect the daily drop trend or any conclusions drawn from the data. Figure VI shows the daily record for the life of these racemes. (July 11 - 30).

It is evident that the drop trend of buds, flowers, and fruits does not agree perfectly with that of temperature or humidity but certain irregularities in the drop curves seem to correlate with these external factors. The initial rate of the drop of buds and flowers is much higher than would be expected in racemes just starting to flower since the highest set normally occurs on the

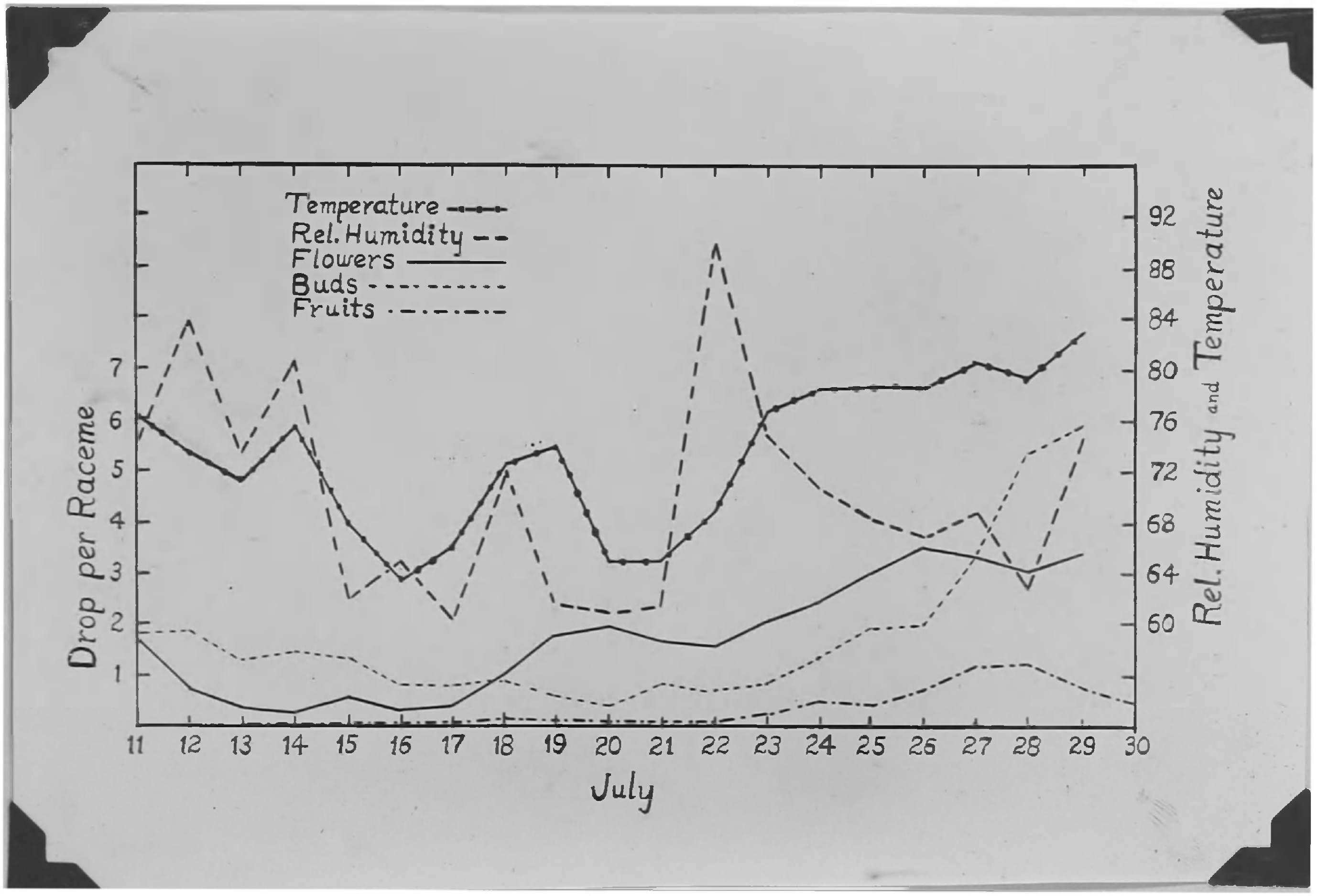

Figure VI — The daily trend of the drop of buds, flowers, and fruits in relation to temperature and relative humidity. These data are based on racemes apparently of the same age and stage of development which first flowered on July 10.

first nodes which were flowering at this time. This increased rate of drop corresponds to a high mean temperature which for July 9 and 10 (not shown in the figure) was above 80°F. Other cases are found where the rate of drop of flowers appears to be affected by temperature. Assuming that there is a lag of one day between the time that temperature exerts its harmful influence and the time it appears in the drop record we have an increased drop on July 15 corresponding to high temperature on the 14; similarly high drop on July 19 and 20, corresponding to the high temperatures on July 18 and 19.

The rapid rise in the rate of dropping of buds and the decline in the drop of flowers during the last few days (26th et. seq.) is probably related with internal factors previously discussed. It was observed that as the flowering approached the terminal of the racemes, there was a tendency for the bud drop to increase with fewer developing to the flower stage.

The total drop and set per raceme was calculated and is presented in Table IV.

TABLE IV — THE EXTENT AND NATURE OF THE DROP IN HENDERSONS BUSH LIMA

Data on 300 Racemes (1929)	Average Per Raceme.	Percent of Total.
	Number.	Percent.
The Drop of:		
1. Buds, - - - - - - - - -	20.81	39.29
2. Flowers, - - - - - - -	23.96	45.23
3. Fruits, - - - - - - - -	3.84	7.25
Fruits Developed, - - - - -	4.36	8.23
Total, - - - - - - - - - - -	52.97	100.00

The results presented in Table IV indicate that these racemes with an average of about eighteen nodes had the potentiality of producing around fifty-three fruits each. Actually they set about eight percent of this number. It is obvious that a great excess of reproductive structures are produced by the racemes, in fact, if they were all set and developed to mature fruits each raceme would be carrying almost as many fruits as the entire plant normally sets. The set for the sixty plants used in this study averaged 55.1 fruits. The total number of racemes the plants produced was not ascertained but similar plants seeded at the same time in adjacent rows averaged over twenty-seven each, thus the probable set per raceme considering all racemes was about two fruits. Therefore it appears that the determinate racemes used in the study actually set twice as many fruits (over four per raceme) as the average for all the racemes of the plant, in spite of the loss of over ninety per cent of the potential fruits in the drop.

Table IV also shows almost forty percent of the abscissions occurred prior to pollination suggesting that the drop cannot be explained entirely on the basis of absence of gametic union or embryo abortion.

The results of this study clearly indicate that a great excess of floral structures are produced on the racemes of Henderson Bush Lima beans and that their dropping is associated with the normal flowering and fruiting habit. The flowering period is long and as a result early set fruit attains considerable size, and hence large food and nutrient requirements while the raceme is still flowering. It seems logical to conclude that the increased rate of drop as the blossoming period progresses is a direct result of the monopolizing of food materials by the developing fruit; the barrenness of the terminal portion of the raceme resulting. Similar conditions have been recorded in other plants such as the tomato. Murneek (19), the spider flower, Murneek (18), the muskmelon, Rosa (2), and eggplants, Smith (24).

There is some suggestion that the daily rate of the drop and possibly the number of fruits set in Lima beans are influenced by temperature and humidity similarly to tomatoes as examplified by the work of Radspinner (21) and Smith (23). The long blossoming period of the raceme and its persistence in flowering, especially in Henderson Bush Lima, are a great protection against short periods of adverse weather.

The fact that dropping is common to all stages of development suggests that certain physiological factors are responsible but on the other hand does not preclude the possibility of the drop being augmented by internal factors. There is also the possibility of the peculiar physiological condition responsible for the drop being associated with certain external factors.

GROWTH, YIELD, AND THE SET OF FRUITS IN RELATION TO TIME OF PLANTING.

In the previous discussions it was intimated that such climatic factors as temperature, relative humidity, and precipitation affect the vegetative growth of Lima beans and possibly influence the set of fruit. In any case the total yield of the crop would be affected. Previous investigations with other vegetable crops furnish evidence proving that variations in the time of planting result in divergent behavior and yield on account of the differences in the external environment under which the plants develop. Successive plantings therefore appeared to be a convenient way to study the relation of temperature, humidity and precipitation to growth, yield, and set of fruit.

Methods. Time of planting studies were carried out in 1929, 1930, and 1931, using the variety Hendersons Bush Lima. The soil and general cultural methods for three years were similar and briefly were as follows: An apparently uniform, sandy loam soil of moderate fertility was used and plantings made at about weekly intervals. The rows were three feet apart in which seeds were planted in hills ten to twelve inches apart. Usually three seeds were placed in each hill and later the seedlings were thinned to one. This planting distance is greater than that commonly used for the variety, but since data were to be taken on individual plants it was considered advisable to use a uniform planting distance and to reduce plant competition to some extent.

The consecutive plantings were made in such a way that they were in adjacent rows in order to facilitate the comparison of any one planting with the preceding or following one. The rows were replicated throughout the field once in 1929 and three times in 1930 and 1931. Blocks with a maximum of six rows were used so that rows of any two plantings which were to be compared were never more than fifteen feet apart. The plants were cultivated shallowly with a wheel hoe and sprayed with magnesium arsenate to control the Mexican bean beetle.

Temperature and humidity data were secured by means of a self-recording hygrothermograph placed in a shelter in the field about twelve inches above the surface of the ground. The mean temperature and humidity were calculated from planimeter readings of the hygrothermograph charts.

Time of Planting Studies -- 1929.

The material for this study comprised eight rows, 110 feet long, made on four planting dates -- May 24, May 31, June 14, and June 28. Each row was divided into ten plots of ten plants each and alternate plots harvested at what was judged to be the best canning stage. In harvesting (green) the plants were cut off at the surface of the ground and weighed. The fruits were immediately removed, counted, and weighed. The plants in the remaining plots were left in place until the fruits ripened and dried. They were then harvested and the number of fruits per plant and weight of shelled beans per plot were ascertained.

The yield data, along with that for temperature and rainfall, are given in Table V. Unfortunately with the exception of the May 24 planting the date of blossoming was not recorded. However the time of blossoming for the other plantings can be approximated within a range of two or three days and by reference to the daily temperature records it is probable that the third planting (June 14) flowered under conditions of highest temperature (mean of about 79°F), with little difference in the temperature of the flowering periods for the remaining three, which ranged between 73° and 75°F.

It is not likely that the differences in the yield of fruits for the four plantings could be attributed entirely to temperature differences during their respective blooming periods or to that for their entire life. The data on rainfall as given in Table V offer no adequate explanations for the low yield of the June 14 planting but since the climatological records show that of the 9.38 inches of rainfall occurring between May 24 when planting began, and September 14 when the last green

TABLE V -- GROWTH AND YIELD IN RELATION TO TIME OF PLANTING.

Date Secured (1929)	Date Planted.			
	May 24	May 31	June 14	June 28
Harvested Green:				
Mean temperature, seeding to harvest (F°) - - - - - - - - -	72.25	72.30	73.25	73.53
Precipitation, seeding to harvest (inches) - - - - - - -	9.95	9.04	8.88	4.98
Weight of plant (less fruit) (grams), - - - - - - - - - - - -	179.9	190.9	149.7	120.3
Weight of fruit (grams) - -	189.9	162.1	146.2	111.2
Average weight per fruit (grams), - - - - - - - - - - - -	3.26	2.65	2.83	2.99
Fruits per plant, - - - - - -	58.2	61.2	51.7	37.2
Efficiency Ratio:				
Weight of fruit / weight of plant, - - - - - - - - - - - - -	1.055	0.849	0.976	0.924
Number of fruits / weight of plant, - - - - - - - - - - - - -	0.324	0.321	0.345	0.309
Harvested Dry:				
Fruits per plant, - - - - - -	54.8	61.30	50.2	41.2
Weight of shelled beans per plant (grams) - - - - - - - -	50.3	55.6	44.8	33.1

harvest was made, 6.38 inches fell before July 1. This unequal distribution of moisture throughout the growing season accounts for the decrease in the size of the plants and the number of fruits set for the last two seedlings. The efficiency of the plants in fruit production as expressed by the ratio of fruit weight to plant weight was relatively high for all plantings. The difference between that of May 24 and May 31 was due mainly to a greater average size per fruit for the first planting which was 3.26 grams compared with an average weight of 2.65 grams for the fruits of the latter planting. The ratio of number of fruits to weight of plant was almost identical for the two. The yield of ripe fruits agree quite well with that for the canning stage harvest and show the same trend. The odds calculated by Students Method indicate that the difference in yield of fruits per plant for any two plantings is significant with the exception of the first two plantings. Thus when planting was delayed beyond May 31 a significant decrease in yield resulted. This decrease in weight and number of fruits per plant corresponds with a decrease in the weight of the vegetative part of the plant. With temperature fairly uniform for the life periods of the plantings it appears that moisture was the principal climatic factor affecting the vegetative growth and yield.

Time of Planting Studies in 1930 and 1931

The data taken in 1929 were inadequate for establishing any direct relationship between weather and the proportion of blossoms which set fruit. Therefore in 1930 the scope of the study was enlarged to ten plantings and more detailed data were taken on the plants. By planting at weekly intervals from May 10 to July 12 the growth of the plants was extended over the entire growing season and the climatic conditions for the blooming periods of the different plantings were as varied as could be secured in one year.

Methods. In conjunction with the time of planting study fertilizers were applied. Sodium nitrate and acid phosphate were applied singly, other plots were untreated; the rows planted at weekly intervals tranversed these plots. Briefly the field plots in 1930 and 1931 consisted of two areas 60 x 132 feet extending north and south joined end to end. Each area was divided into twelve plots 21 x 33 feet each and arranged in the area in a three by four fashion. The fertilizer treatments were distributed systematically among these small plots. The outside rows of these plots were planted as guard or buffer rows on May 10 simultaneously with row number one within each plot. Thus this first planting and subsequent plantings were represented by three rows equally distributed across the 63 foot width of the area and extending the full length of 132 feet. The first six plantings (May 10 to June 14) were made in the south area and those of June 7 to July 12 planted in the north area. It should be noted that the fifth and sixth plantings were common to both the north and south areas. Figure VII shows the north area in the foreground with the last (July 12) seeding on the extreme left and the June 7 planting on the

Figure VII -- General view of the plots on July 26, 1931, showing the arrangement of the various plantings. The late seedings of the north area are in the immediate foreground.

extreme right. In the south area beyond, the May 10 planting is an extension of the June 7 row of the north area. Again on the left the June 7 planting (of the south area) corresponds to the row seeded July 12.

The rate of emergence was determined by a count of the number of hills in which seedlings were evident at the end of seven and nine days. This was compared with the final stand. The date that flowering began was noted and the number of plants showing open flowers was determined by count every second day until practically all were flowering. The date that seventy-five percent of the plants were flowering is considered as the flowering date of the planting as a whole.

All plants were harvested when the fruit was at the canning stage of development. Thirty plants were removed from each plot row, leaving two buffer plants at the junctions of the plots. Because many plants were handled (360 per planting date) and detailed data were taken it was impractical to handle them in the field, and therefore the plants were cut off and placed in tall, narrow hampers encased in moist burlap bags. Usually three plots were harvested at a time and the plants then taken to the laboratory near the field where the final data were taken. All precautions were observed to avoid loss of weight in plants and fruits.

All plants were weighed individually from the hampers. The fruits were pulled off, every second plant counted and weighed. The racemes were clipped off the remaining plants, and the number and position of fruits set on each determinate raceme recorded along with number of fruits on each indeterminate raceme. The number of unfruitful determinate and indeterminate racemes was also tabulated. As these data were taken the fruits were removed and placed in individual containers and weighed.

With two assistants the three phases of this work were carried on simultaneously and the time required to handle the thirty plants of one plot was usually not over forty-five minutes. The twelve plots of each planting were harvested over a period of one or two days removing the more advanced plots first when any difference in maturity was noted.

The methods used in 1931 were essentially the same as that just described except that the harvest records were secured in a shelter constructed beside the field and only one plot was harvested at a time, thereby reducing the time interval between harvesting and weighing. Date on racemes were taken from every sixth plant making a total of sixty for each planting.

Figure VIII represents the daily precipitation the mean temperature for 1930 and 1931. The life periods for the various plantings are given in the lower half of the figures. The two seasons were extremely

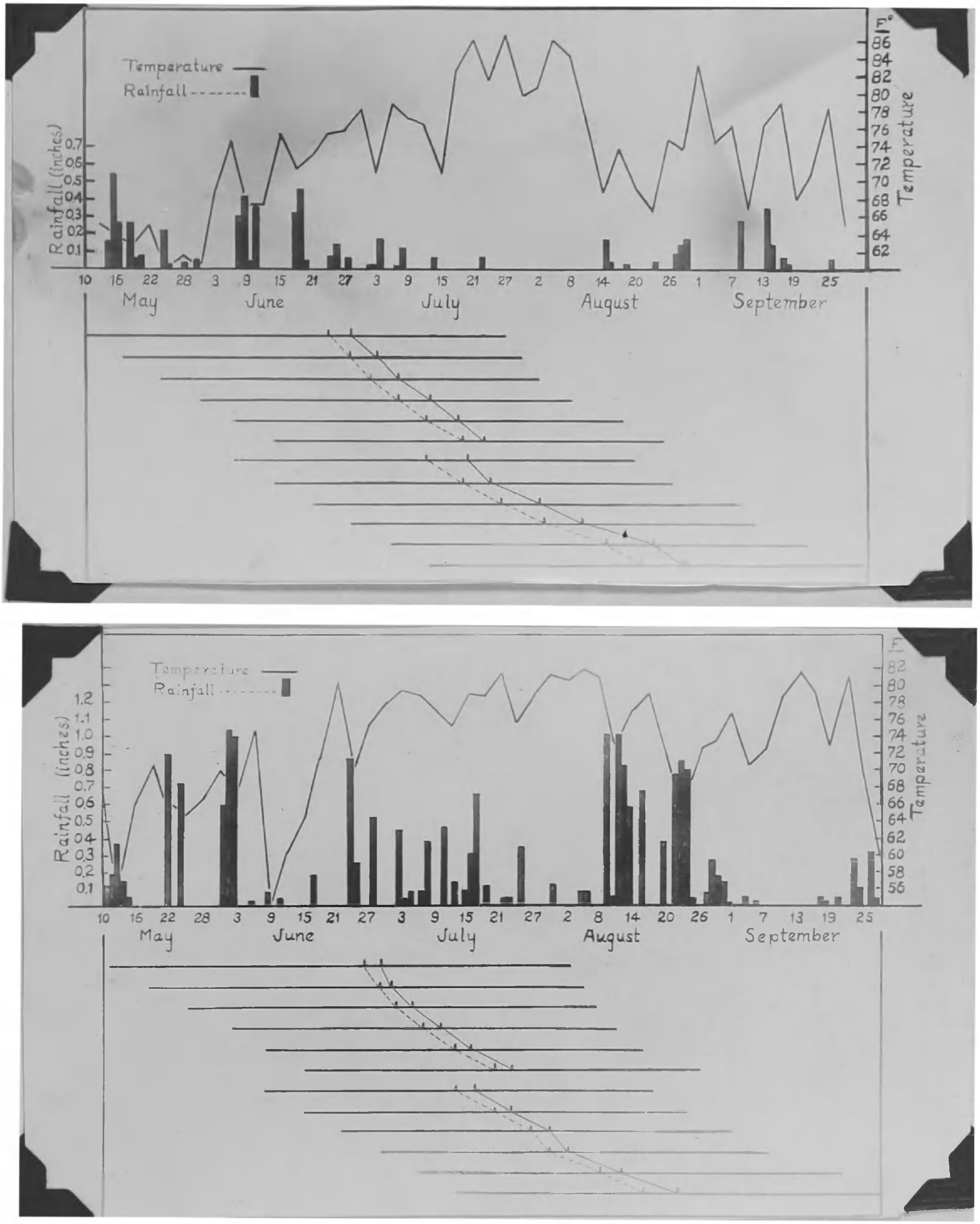

Figure VIII — Rainfall and mean temperature data for the seasons 1930 (above) and 1931 (below). The life periods for the ten plantings are represented as horizontal lines. The time flowers appeared (connected by dotted line) and the time 75 percent of the plants were flowering (___ by solid line) are given.

different especially with respect to rainfall. The severe drought of 1930 contrasting with the ample rainfall of 1931. In the former the moderate precipitation of May and June dwindled to practically none in July and early August. That of late August and September was much below normal. Extremely high temperature in Jyly served to intensify the drought. Both temperature and precipitation were more agreeable for crop development in 1931.

Rate of Growth and Maturation in Relation to Temperature. From Figure IX it is apparent that the time elapsing between seeding and flowering, and flowering and harvest is variable throughout the various plantings. Numerous studies have demonstrated that the rate of growth and maturation is associated with temperature. Boswell (2) has shown that the early maturity of peas induced by high temperature is accompanied by a reduction in the size of plant and yield of fruits. Because the set of fruit in Lima beans, as has been shown, is intimately associated with development of the plant, it was desirable to consider the influence of temperature on the rate of growth and maturation. This was evaluated by means of the remainder indices where in the temperature accumulations above 40°F were calculated for two life periods of the plants.

Table VI is presented to facilitate a comparison of the time required for the completion of the various stages in the life cycle with the mean temperature and heat summations.

TABLE VI — RELATION OF TEMPERATURE TO RATE OF GROWTH AND MATURATION OF HENDERSON BUSH LIMA.

Date Planted, (1930)	90% Emerged	Emergence to Flowering.			Flowering to Harvest.			Seeding to Harvest.		
		Time	Temp.	Heat Summation	Time	Temp.	Heat Summation	Time	Temp.	Heat Summation
	Days.	Days	F°		Days	F°		Days	F°	
South Area:										
May 10,	12	37	69.14	1137	30	79.17	1175	79	73.50	2312
May 17,	11	36	71.02	1176	27	80.22	1078	74	74.81	2254
May 24,	10	34	73.34	1208	26	80.50	1014	70	76.41	2222
May 31,	11	32	74.33	1146	26	82.36	1099	69	78.16	2245
June 7,	11	31	75.69	1135	31	80.77	3152	72	78.11	2847
June 14,	9	30	77.45	1124	33	77.90	1332	72	77.69	2456
North Area:										
June 7,	11	32	75.69	1178	30	80.77	1309	73	78.11	2487
June 14,	9	31	77.45	1166	33	77.90	1321	73	77.69	2487
June 21,	10	33	79.50	1201	37	75.85	1359	80	77.59	2560
June 28,	10	33	81.10	1342	32	73.28	1061	75	77.74	2403
July 5,	11	38	79.30	1428	31	73.65	1084	80	75.85	2512
July 12,	10	38	77.66	1408	33	73.87	1143	81	76.84	2545
1931 South Area:										
May 11,	12	38	69.16	1069	35	78.70	1363	85	73.53	2432
May 18,	11	33	70.54	1002	35	78.95	1374	79	74.56	2376
May 25,	10	30	71.53	987	34	78.18	1349	74	75.19	2336
June 2,	10	28	73.87	935	32	79.82	1284	70	76.65	2219
June 8,	10	29	77.42	1008	30	79.38	1222	69	78.45	2230
June 15,	10	28	78.21	1060	34	76.96	1283	72	77.55	2343
North Area:										
June 8,	11	28	77.42	.988	32	79.43	1208	70	78.48	2206
June 15,	10	28	78.21	1015	32	77.41	1231	70	77.81	2246
June 22,	11	27	78.87	982	33	75.99	1235	71	77.36	2217
June 29,	10	25	79.05	967	36	74.83	1282	71	76.64	2249
July 6,	10	26	79.59	1031	41	74.93	1457	77	76.84	2488
July 13,	10	30	78.65	1241	38	73.49	1303	78	75.85	2444
AVERAGE 1931	10.40	29.1	76.04	1025	34.3	77.34	1299	74.7	76.58	2324
AVERAGE 1930	10.33	33.8	75.97	1203	30.8	78.03	1194	74.5	76.84	2414

The time interval between seeding and emergence, emergence and flowering, etc. varies inversely with the mean temperature, while the value of the heat summation is fairly constant. With the exception of the flowering to harvest period for the 1930 plantings, maturation is more rapid for the intermediate plantings and less rapid for those made at the beginning and the end of the planting season.

The averages at the bottom of the table are helpful in comparing the results for the seasons. The average number of days from planting to harvest was almost identical, likewise the time elapsing between seeding and emergence. The emergence to flowering period was longer for 1930 with a corresponding decrease in the flowering to harvest stage. Presumably the deficiency of moisture and possibly super-optimum temperatures during mid-summer caused a reduction in the efficiency of the plants with respect to the utilization of heat and light. The retarding in the growth rate is especially noticeable in the late plantings for 1930 and the heat summations for these plantings are also abnormally high.

<u>Vegetative Growth and Yield of Fruits as Affected by Time of Planting</u>. The rapid rate of maturation as a result of high temperature results in the reduction in vegetative growth and fruiting in some plants. This may be true to some extent for Lima beans but as suggested in the data secured in 1929 and 1930, the moisture supply

[redacted]

Table VII — RELATION OF TIME OF PLANTING TO VEGETATIVE GROWTH AND YIELD OF FRUITS.

Planting Date (1930)	Average Per Plant.				Precipitation (inches)			Efficiency Ratio		Coefficient of Correlation*
	Plant Wt. Grams	Fruit Wt. Grams	No. of Fruits	No. of Racemes	Planting to Flowering	Flowering to Harvest	Planting to Harvest	Wt. Fruit / Wt. Plant	No. Fruit / Wt. Plant	
South Area:										
May 10,	—	—	38.1	—	3.94	0.53	4.47	—	—	—
May 17,	146.0	117.7	37.3	21.3	3.19	.31	3.50	0.806	0.255	.72 ± .05
May 24,	132.6	100.4	35.0	21.4	2.95	.16	3.11	.757	.262	.49 ± .09
May 31,	118.3	83.5	31.0	18.5	2.64	.16	2.80	.695	.262	.66 ± .06
June 7,	113.7	93.0	30.8	21.7	2.62	.32	2.94	.819	.270	.96 ± .01
June 14,	87.4	78.7	30.4	16.6	1.69	.28	1.97	.899	.348	.78 ± .04
North Area:										
June 7,	88.8	64.9	27.1	19.9	2.62	.32	2.94	.731	.306	.80 ± .04
June 14,	76.7	63.8	25.8	14.9	1.69	.28	1.97	.833	.337	.87 ± .03
June 21,	57.3	49.9	18.8	17.7	.85	.99	1.84	.870	.328	.89 ± .02
June 28,	49.6	44.9	15.2	13.2	.53	.99	1.52	.908	.307	.94 ± .01
July 5,	46.9	47.3	17.9	15.5	.55	1.34	1.89	1.010	.381	.92 ± .02
July 12,	33.5	35.9	12.6	13.1	.44	1.34	1.78	1.074	.376	.93 ± .01
(1931)										
South Area:										
May 11,	165.3	150.4	51.3	31.2	7.12	3.33	10.45	.842	.311	.81 ± .05
May 18,	171.3	141.1	47.8	31.2	6.73	3.05	9.78	.821	.279	.79 ± .04
May 25,	155.4	126.7	43.6	28.8	6.67	2.96	9.63	.819	.280	.79 ± .04
June 2,	171.4	161.6	47.7	30.4	5.59	2.96	8.55	.944	.278	.86 ± .03
June 8,	175.6	175.3	47.0	31.8	4.71	4.88	9.59	.999	.267	.93 ± .02
June 15,	173.6	144.1	40.3	32.5	4.94	7.25	12.19	.863	.232	.55 ± .08
North Area:										
June 8,	177.7	148.2	42.3	31.2	4.71	4.88	9.59	.849	.238	.56 ± .08
June 15,	176.7	148.5	40.5	32.9	4.94	7.25	12.19	.842	.229	.03 ± .10
June 22,	167.8	153.1	44.1	33.4	4.45	7.87	12.32	.915	.263	.63 ± .07
June 29,	198.6	149.3	48.5	39.6	3.02	7.78	10.80	.843	.244	.04 ± .11
July 6,	177.0	156.7	49.8	41.2	6.35	4.72	11.07	.886	.281	.55 ± .08
July 13,	121.3	135.4	40.1	32.0	6.04	4.50	10.54	1.082	.330	.82 ± .04
AVERAGE 1931	169.3	149.2	45.24	32.01	5.44	5.12	10.55	.892	.270	.614
AVERAGE 1930	86.4	70.4	26.7	17.62	1.98	0.59	2.56	.855	.312	.815

* — Number of fruits with weight of plant.

[redacted]

was the one factor most closely associated with yield of plant and fruits.

Table VII contains the yield and precipitation data for the seasons 1930 and 1931. In 1930 the growth of the plants of all plantings was limited by rainfall which decreased as the season advanced. For the first eight plantings very little precipitation occurred during the fruiting period. Thus the weight of the vegetative part of the plant and its fruit decreased in proportion to the decline in rainfall. Belated rains coming in August arrived at a critical time in the life of the plants of the ninth seeding, increasing the yield of fruits over that of the preceding planting.

Further evidence of the influence of moisture on development and yield is found in a comparison of the north and south areas of the field with respect to the June 7 and June 14 plantings which were common to both areas. The north area being on the high end of the slope was the first to give evidence of a moisture shortage and a proportionate decrease in yield resulted. No such difference occurred in 1931.

It is evident that both the weight of the vegetative part of the plant and its fruits decreased as the planting was delayed but the former declined more rapidly than did the latter. The weight of the plant appears to be more closely associated with the precipitation of the emergence to flowering period while the weight of the fruit is affected more by the precipitation during the period of fruit development. Thus we find the ratio of weight of fruit / weight of plant reaching a maximum with the last planting. This increase in efficiency is not entirely due to better development of the fruit, however, since the ratio of number of fruit set to the weight of the plant increases for the late seedings.

The correlation between number of fruits set and the weight of the plant was high for all plantings indicating that the yield of fruits is affected to a great extent by the size of the plant and probably the number of racemes produced. This correlation was greatest for the late plantings as if the moisture factor was becoming predominate eliminating others which might affect vegetative growth or set of fruit independently of the other.

An abundant rain fall for all the plantings in 1931 produced entirely different results in growth and yield. As an average the 1931 plantings received about five times the amount of moisture of the plantings in 1930. The precipitation for the period of fruit development was increased over nine fold. This favored fruit production as indicated by the fruit / plant ratio. On the other hand an abundance of moisture during the early life of the plants stimulated vegetative growth out of proportion to fruit set as indicated by the fruit set / plant weight ratio.

The average weight of the plant, weight of fruit and number of racemes as an average was increased practically 100 percent over the 1930 values where as the set of fruit per plant was increased slightly over 75 percent. Again the coefficient of correlation of set of fruit with weight of plant was decreased.

This study substantiated by that of 1929 indicates that precipitation (especially during the pre-flowering period) is an important factor in determining the extent of the vegetative development of the plant. Thus in spite of high temperature (See Table VI) a large plant is produced in the presence of an ample supply of moisture. The high correlation between number of fruits set and the size of the plant suggests that in so far as Hendersons Bush Lima is concerned, variations in the size of the plant usually affect the total yield of fruits more than variations in the set of fruit per raceme. In the widely different seasons of 1930 and 1931 which produced a 100 percent difference in yield in favor of the latter year, the set of fruit per raceme was insignificantly different.

The Set of Fruit in Relation to Time of Blossoming. The previous data and discussion indicated that the rate of maturation of the plants was affected by temperature, but that the size of the plant varied more directly with the precipitation during the vegetative part of the life cycle. Although the number of fruits produced was closely associated with plant size, the relationship was not absolute and the possibility of deviations in the set of fruits per raceme was suggested. In the light of the data on the daily rate of the blossom drop already presented it seems likely that if variations should occur in the set of fruits per raceme for the various plantings they would bear some relation to the temperature and the relative humidity of the blooming period.

Table VIII contains data taken on the raceme basis which is presented for comparison with the mean temperature and relative humidity for the first twelve days of the flowering period. A twelve day interval was taken because it represents the most active part of the flowering and fruit setting period. Unfavorable weather at this time might result in a reduction in the set of fruits per raceme on a shift in the position of the set on the raceme or both a reduction and a change in the position of the set.

The data show that there was a tendency for the set of fruits per fruitful raceme to decrease as the mean temperature of the flowering period increased. This is true to some extent for the average based on all racemes, but since the percent barren racemes varied more or less independently of the mean temperature, this association is not so close. As has been shown previously the extended flowering period of the raceme,

Table VIII — INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON SET OF FRUIT.

Date Planted (1930)	12 Day Mean.		Racemes Per Plant.			Fruits Per Raceme.		Ratio: Temp. / Humid.	Mean Position of Set.
	Temp.	Humidity	Fruitful	Unfruitful	% Unfruitful	All Racemes	Fruitful Only.		
	F°	Percent							Nodes
South Area:									
May 10,	76.06	63.38	—	—	—	—	—	1.16	—
May 17,	76.00	62.89	10.22	11.04	52.35	1.75	3.24	1.21	2.66
May 24,	77.00	61.44	11.84	9.84	44.84	1.64	2.73	1.25	2.39
May 31,	79.25	63.21	11.69	11.69	37.03	1.68	2.43	1.26	2.67
June 7,	84.63	58.89	9.41	9.41	41.59	1.42	2.21	1.44	2.96
June 14,	82.50	58.01	12.71	12.71	20.21	1.83	2.33	1.42	3.76
North Area:									
June 7,	83.90	58.89	12.59	7.38	37.02	1.36	2.18	1.43	4.32
June 14,	82.50	58.01	11.45	3.64	24.47	1.74	2.15	1.42	4.41
June 21,	82.80	52.78	9.60	7.98	45.21	1.07	1.94	1.56	4.03
June 28,	78.25	57.83	6.82	6.33	47.50	1.57	2.25	1.35	4.18
July 5,	74.81	64.33	9.14	6.29	40.88	1.15	2.03	1.16	3.36
July 12,	76.75	61.38	6.36	4.77	42.85	0.96	2.07	1.25	2.47
(1931)									
South Area:									
May 11,	78.16		19.28	11.93	37.61	1.66	2.35		2.48
May 18,	77.46		18.15	13.00	41.72	1.63	2.47		2.38
May 25,	77.44		16.83	11.92	41.42	1.56	2.42		2.23
June 2,	78.68		15.68	14.75	48.41	1.63	2.68		2.35
June 8,	78.78		16.37	15.43	48.61	1.54	2.57		2.35
June 15,	79.06	75.46	16.30	16.23	49.87	1.38	2.41	1.05	2.66
North Area:									
June 8,	78.78	—	14.56	16.66	53.37	1.37	2.61	—	2.46
June 15,	79.06	75.46	15.32	17.53	53.02	1.30	2.42	1.05	2.65
June 22,	81.16	75.08	18.18	15.19	45.48	1.23	2.24	1.08	3.36
June 29,	79.13	76.92	21.37	18.26	46.09	1.30	2.21	1.03	3.94
July 6,	75.15	79.46	21.40	19.82	48.45	1.22	2.17	0.95	3.76
July 13,	71.95	74.75	15.20	16.75	53.74	1.18	2.30	0.96	3.29
AVERAGE 1931	77.90		17.38	15.62	47.32	1.42	2.40		2.83
AVERAGE 1930	79.81	59.79	10.17	6.99	39.45	1.47	2.32	1.34	3.38

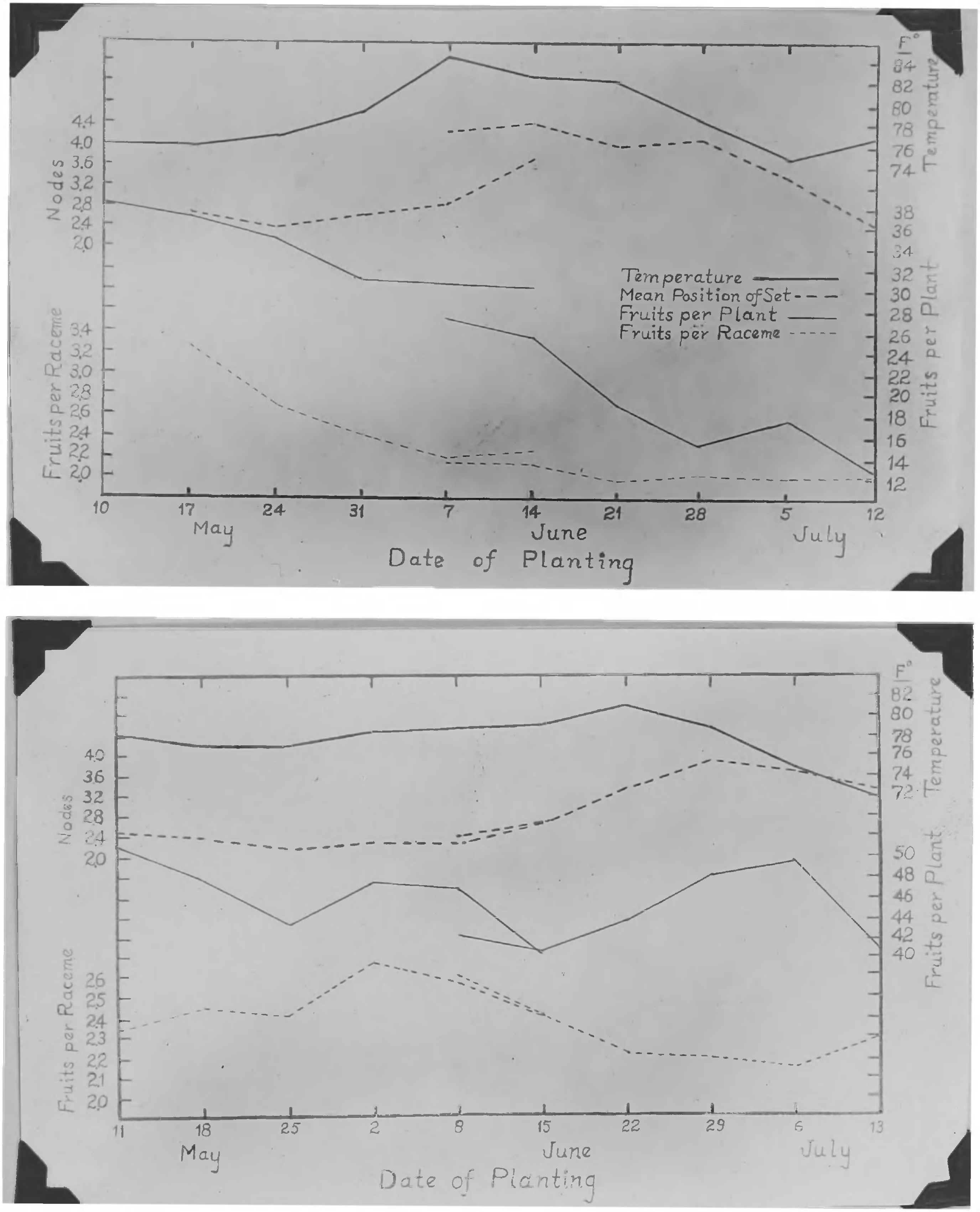

Figure IX -- A comparison of mean temperature of the first twelve days of the flowering period with the mean position of the set of fruits on the raceme, the average number of fruits per plant, and the set of fruits per fruitful raceme. Data taken in 1930 above, 1931 below.

which may cover an interval of twenty days is a great insurance of fruitfulness in the advent of short periods of unfavorable weather. Thus the set per raceme may be unaffected but the position of the set will be varied. Figure IX shows that as the mean temperature of the flowering period increased the set of fruit advanced toward the terminal and the set per fruitful raceme decreased. The "mean position of the set" was determined by calculating a mean with the nodes of the raceme as the class intervals and the fruits set on these nodes as the frequencies. It is apparent from the graph that there is little if any relationship between the number of fruits per plant and the mean temperature of the flowering period. As has already been shown, the yield of fruits is affected more by the size of plant and the number of racemes.

Figure X. illustrates the two extremes of the ten plantings of 1930 and 1931 in regard to the position of the fruit set. In the case of the early planting which flowered with a low mean temperature, a prompt set confined the fruit to the basal nodes. High temperature during the flowering period of the later planting delayed the set and as a result the fruit is distributed more toward the terminal. Just why the set was not delayed indifinitely is not shown by the data, but it is possible that as flowering continued more favorable conditions were encountered and fruit set. This suggests that setting

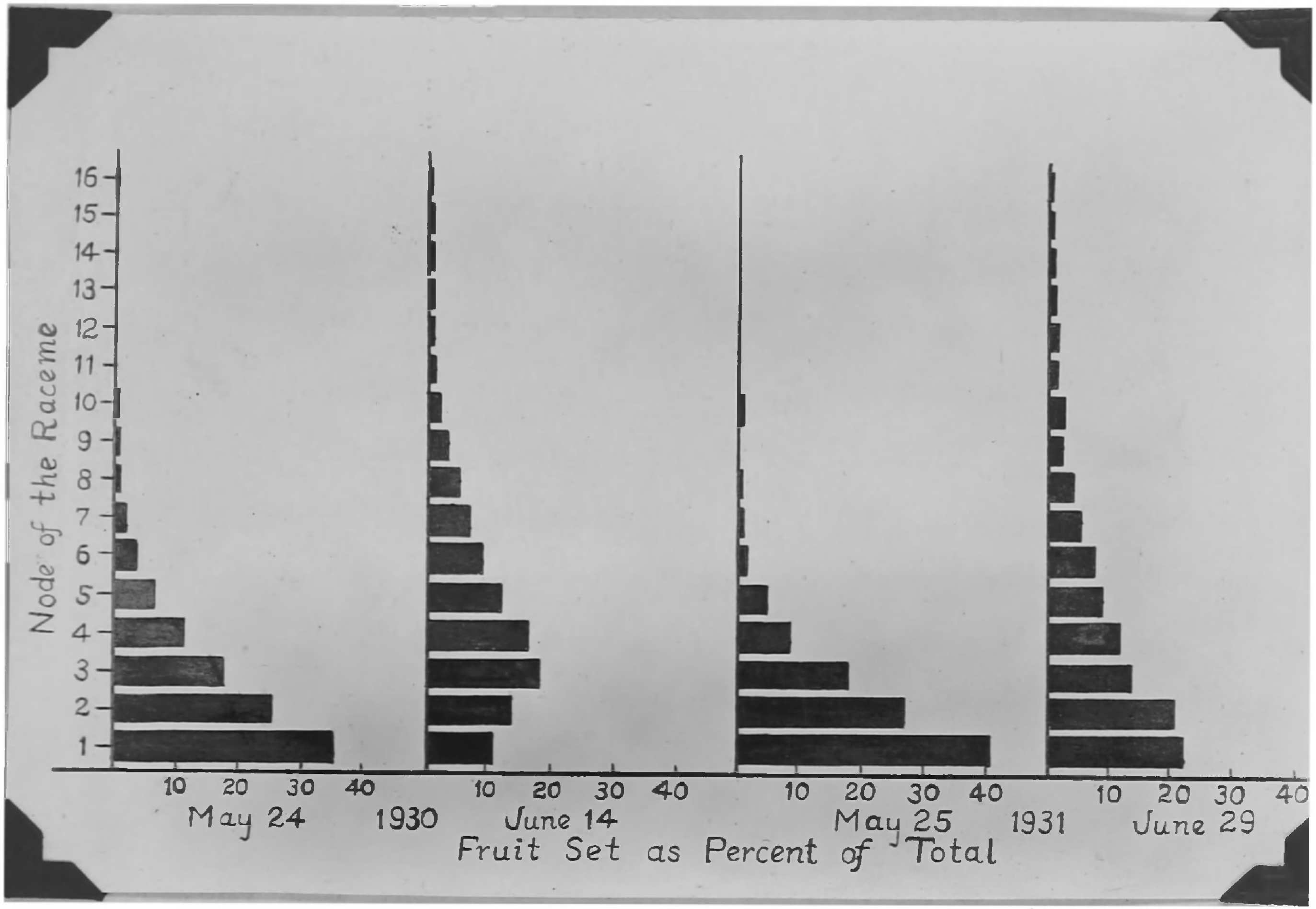

Figure X -- Set of fruit according to position on the raceme. The two extreme plantings with respect to the position of the set for 1930 are represented at the left. Fruit set occurred more promptly in similar plantings made in 1931. (right)

might occur intermittently on the raceme corresponding to days of more favorable temperatures. It is true that irregular set of this nature was observed in many racemes but enough variation occurred to entirely mask this periodic tendency in these averages secured on a great number of racemes. Again it should not be inferred that under continued favorable external conditions set continues indefinitely. The data merely indicate that the maximum set normally found on a raceme is attained more promptly.

Humidity alone does not appear to be very closely associated with fruit set but as shown by other investigations as an associated factor with temperature is of considerable importance. Thus high temperature, accompanied by low humidity, would likely be more adverse to fruit set than temperatures equally high but associated with high humidity. The temperature / humidity ratio given in Table VIII if compared with the set per raceme on the mean position of the set, exhibits a closer relationship than does either factor when compared alone. It is apparent that these two climatic factors on inter-related or additive factors in causing the abscission of the reproductive structure of this plant.

The relative number of fruitful and unfruitful racemes produced varied considerably but without establishing a definite relationship with the external factors. It appears that the production of barren racemes,and to some extent, the reduction in the set of any raceme, is a result of the interaction of a multitude of external and internal factors. However a number of racemes are produced which by virtue of their position on the plant, the time they are produced, and the general complexity of the plant, have no potentiality for fruiting. Thus it is possible that the number of barren racemes resulting from these internal factors is greater than that resulting from the destruction of blossoms by unfavorable external conditions.

In regard to this last point additional proof is found in a comparison of the averages fro 1930 and 1931 in Table VIII. The abundance of moisture in 1931 increased the size of the plants to about twice that of the plants grown in 1930. The mean temperature for the flowering periods averaged about two degrees lower and relative humidity was higher. But regardless of the more favorable weather the average percent of barren racemes was about one-fifth more in 1931 than for 1930, indicating that the production of barren racemes was influenced more by the extent of the vegetative development of the plant, which tended to be excessive in 1931, than by the temperature and humidity during the flowering period. On the other hand this increase in unfruitful racemes was accompanied by a scarcely perceptible increase in the set of fruits on the fruitful racemes.

In general higher temperature and low humidity during the flowering periods and a deficiency of moisture throughout the entire season of 1930 decreased the size of the plant, total number of racemes, the percent of unfruitful racemes, and the set of fruits per raceme. Accompanying this reduction in set of fruit its mean position was shifted toward the terminal of all raceme, being 3.38 nodes from the base as an average compared with 2.83 for 1931.

From the results presented it is apparent that unfruitfulness in Lima beans is in general the result of a very complex relationship existing between external and internal factors. Undoubtedly temperature and relative humidity may become potent factors in reducing the set of fruits and lowering the yield of these plants as has been shown to be true in the case of tomatoes. But the long flowering period, and persistent nature of flowering in Henderson Bush Lima are a great protection against short periods of adverse weather. The mere presence of unfruitful racemes on these plants or the dropping of blossoms should not be considered evidence that the plant as a whole is unfruitful or that a crop failure will result. The maximum number of fruits that the plant can mature may be set in spite of a loss of a great number of blossoms and the presence of a barren raceme.

BEHAVIOR OF LIMA BEAN PLANTS AS AFFECTED BY NITROGEN AND PHOSPHORUS

Investigations relative to the influence of mineral nutrients on the composition of plants and their growth, flowering and fruiting responses are abundant. The influence of the nitrogen supply on vegetative and reproductive activities has been shown with many plants. Numerous other studies have shown that phosphorus as well as nitrogen may affect set of fruit and fruit development. Kraybill (10), Hepler (8), and Hepler and Kraybill (9) have shown that the mineral nutrition of the tomato, especially phosphorus may determine the percent of blossoms set and the number of fruits matured. Zimmerley (27) reported increase in yields in snap beans for heavy applications of acid phosphate to acid soils, over considerable range of pH values.

Study Conducted in 1929

Nine rows were layed off adjacent to those described in the time of planting study for 1929. Prior to planting the area was divided into three plots 27 x 42 feet. Acid phosphate (1,000 pounds per acre) was applied to the north plot, that at the south end received sodium nitrate at the rate of 100 pounds per acre prior to planting and an equal amount was applied as a side dressing to the rows at the time the plants began to flower, the remaining plot was untreated. Alternate rows were planted on May 24, and July 28 respectively.

One of the rows planted May 24 was used in a defoliation study. The plants in one-half of the row were given a general partial defoliation, which consisted of clipping out the middle leaflet of each leaf, while the leaves were relatively young. The plants in the remainder of the row were treated by the removal of the entire leaf subtending about half of the racemes, two or three days before blossoming (See Figure XI). Not knowing at the time of defoliation that the potentiality for fruit production was not the same for determinate and indeterminate racemes, defoliation was done indiscriminately/and as a result a greater proportion of the vigorous determinate racemes than indeterminate racemes fell into the defoliated group because they were more accessible for treatment.

The planting distance and cultural practices were the same as described previously. The yield per plant was secured by harvesting the fruits at intervals as they matured and ripened. Where defoliation treatments were used the data were taken on a raceme basis. Table IX contains the yield and set data secured in this study. For the May 24 planting the yields as fruits per plant, were almost identical for the sodium nitrate and untreated plots while both these outyielded the acid phosphate plot. This difference at the time was considered to be due to a

TABLE IX — **FRUIT SET AS AFFECTED BY DEFOLIATION AND APPLICATIONS OF NITRATE AND PHOSPHATE FERTILIZERS.**

Data Secured (1929)	Fertilizer Treatment		
	Sodium Nitrate	Untreated	Acid Phosphate
Yield as Fruits per Plant (Planted May 24)			
1. Not defoliated	61.16	62.04	47.81
2. Plant one-third defoliated	44.94	46.85	41.80
3. Racemes defoliated	44.70	44.11	46.90
Yield as Fruits per Plant (Planted June 28)	35.80	36.59	36.13
Data on Racemes:			
1. Plant one-third defoliated.			
a. Average fruit per fruitful raceme,	1.99	2.13	2.34
b. Average fruitful racemes per plant	21.28	19.05	13.68
c. Percent unfruitful,	25.34	17.71	24.74
2. Racemes defoliated:			
a. Defoliated racemes.			
(1) Number defoliated*	252	290	255
(2) Set of fruit per fruitful raceme	1.63	1.96	2.12
(3) Percent unfruitful	42.86	52.41	42.10
b. Racemes not defoliated			
(1) Number left untreated	267	229	213
(2) Set of fruit per fruitful raceme	1.90	2.09	2.15
(3) Percent unfruitful	7.12	10.48	9.39

* On eighteen plants.

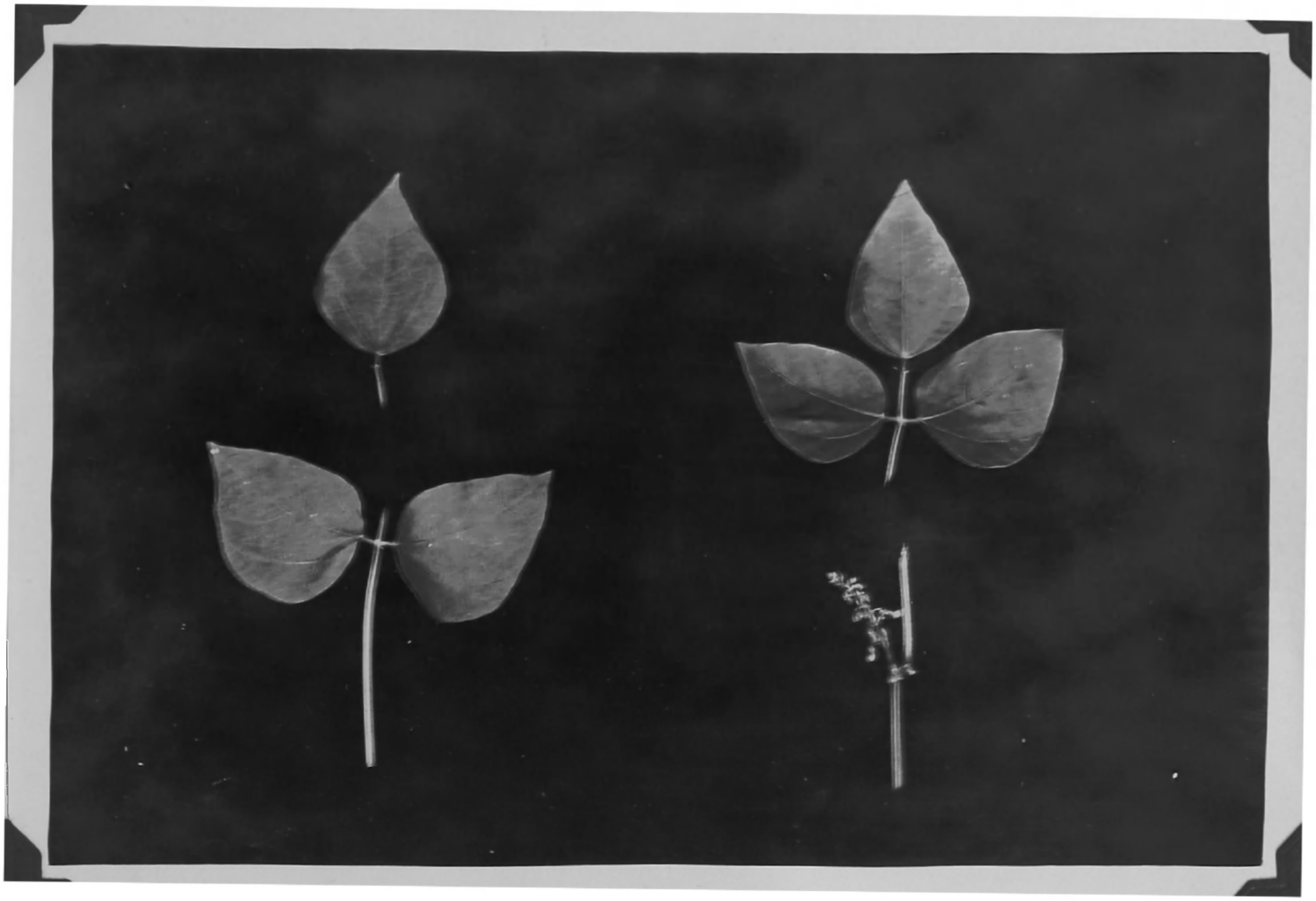

Figure XI — Left, partial defoliation of the plant was accomplished by removing the center leaflet. Racemes were defoliated by removing the entire subtending leaf-right.

difference in soil moisture because the low yielding plot was on the high end of the field and as has already been shown, the rainfall for the latter half of the growing season was very limited in the year 1929. The plants of this low yielding plot ceased growing early and fruits matured and ripened at an earlier date. For example, three harvests of dry fruits were made -- August 18, September 12, and September 20, the percent of the total fruits secured in each harvest was 63.0, 26.3, and 10.7 respectively for the phosphate plot compared with 23.9, 45.7 and 30.4 percent respectively for the nitrate plot.

Little difference in productivity resulted from fertilizer treatments for the planting of June 28. As a whole the yield was much lower than that of the May 24 planting.

Defoliation severely reduced the yield of fruits per plant and especially in the case of the nitrated and untreated plots. The set per raceme was apparently reduced most on those plants fertilized with nitrate. The set on the racemes on the plants of the phosphate plot seemed least affected by defoliation. These plants receiving acid phosphate were smaller, as shown by the total number of racemes produced, were less fruitful, and by chemical analysis proved to be low in nitrogen. Thus defoliation would be expected to affect their set of fruit least.

Where defoliation was localized to the raceme, the set was lower than that for undefoliated racemes on the same plants and undoubtedly there would have been a greater reduction in set had there been a proportional distribution of determinate and indeterminate racemes between the two groups. The influence of defoliation is more strikingly shown in the percentage of barren or unfruitful racemes. Over 45 percent of the defoliated racemes were barren compared with only about 9 percent unfruitful for the undefoliated ones.

The marked reduction in yield resulting from defoliation is presumable brought about by a reduction in the carbohydrate supply and therefore its influence on set of fruit would be modified by the nitrogen content of the plant. When nitrogen is high, reducing the carbohydrate content by defoliation, affected the set more adversely than defoliation in association with only a moderate supply of nitrogen.

The low set and yield of fruits induced by defoliation serves to emphasize the importance of disease and insect control. Reduction in the leaf area as a result of the ravages of these pests, especially the Mexican bean beetle, may readily result in crop failure.

Studies of 1930 and 1931

After 1929 the fertilizer and time of planting investigations were combined as previously described. Acid phosphate was again applied at the rate of 1,000 pounds per acre, sodium nitrate was applied at the rate of 200 pounds in 1930 and 300 pounds per acre in 1931. These quantities of nitrate were divided in two applications as in 1929. Because the plants in the north area responded somewhat differently to the fertilizers than those in the south area, the results for the two areas were summarized separately. The data in growth and yield given in Table X and that for fruit set in Table XI show no consistent effect as a result of the fertilizers used. No difference is found in the set of fruits on a raceme basis. The increased yields on a plant basis in favor of sodium nitrate on the south area and in favor of acid phosphate on the north area, are a result of the production of larger plants, with a greater bearing area, on those plots.

The tendency for the yield of fruits to be low in the acid phosphate plots reoccurred again in 1930 and 1931 on the south area as in the 1929 plantings. No explanation is offered for this result. With the number and arrangement of plots the soil moisture and soil fertility factors should have been eliminated fairly well, but never the less in only one planting, (June 14, 1930) out of the twelve seeded on that part of the field, did the phosphate plots so much as equal the undtreated plots in the production of fruits per plant.

In general the differences in yield in favor of fertilizers under the conditions of this study were lacking in consistency and increase in yield arose only

TABLE X — GROWTH AND YIELD OF BEANS AS AFFECTED BY SODIUM NITRATE AND ACID PHOSPHATE (1930-1931)

Treatment (1930)	Average Per Plant.				Efficiency Ratio		Ceofficient of Correlation*		Odds: (Fruits per Plant)
	Wt. of Plant Less Fruit	Wt. of Fruits	No. of Racemes	No. of Fruits	Wt.Fruit / Wt.Plant	No.Fruit / Wt.Plant			
South Area:									
Sodium Nitrate	123.0	100.3	19.8	35.73	.815	.290	.550	.062	$NO_3 > PO_4$ = 54:1
Untreated,	121.8	97.3	19.7	33.92	.799	.278	.695	.045	$NO_3 >$ Unt = 12:1
Acid Phosphate	114.1	87.0	18.7	31.59	.762	.277	.669	.055	
North Area:									
Sodium Nitrate	56.20	48.49	15.2	18.63	.863	.331	.706	.040	
Untreated,	58.47	51.93	14.8	19.33	.888	.331	.880	.028	
Acid Phosphate	62.57	52.90	16.25	20.79	.845	.332	.894	.016	
Treatment (1931)									
South Area:									
Sodium Nitrate	182.4	160.2	32.8	48.59	.878	.250	.483	.064	$NO_3 >$ Unt = 15:1
Untreated,	178.3	155.2	31.9	47.77	.870	.268	.657	.047	Unt $> PO_4$ =9999:1
Acid Phosphate	152.3	134.2	28.2	41.45	.881	.272	.648	.047	$NO_3 > PO_4$ =9999:1
North Area:									
Sodium Nitrate	168.4	149.3	34.6	45.01	.887	.267	.622	.049	$PO_4 >$ Unt = 14:1
Untreated	163.1	143.4	35.9	42.57	.879	.261	.579	.053	$PO_4 > NO_3$ = 1.5:1
Acid Phosphate	176.5	158.3	35.1	45.47	.879	.258	.460	.063	

* Number of fruits with weight of plant.

TABLE XI -- DATA ON RACEMES AND FRUIT SET -- FERTILIZER SERIES 1930-1931

Treatment (1930)	Racemes Per Plant			Fruits Per Raceme		Fruits Per Plant.
	Fruitful.	Unfruitful.	Percent Un-Fruitful	Fruitful Only	All Racemes	
South Area:						
Sodium nitrate,	11.80	8.04	40.52	3.03	1.80	35.73
Untreated,	11.03	8.63	43.90	3.08	1.72	33.92
Acid phosphate,	10.96	7.60	40.95	2.88	1.69	31.59
North Area:						
Sodium nitrate,	9.03	6.21	40.75	2.06	1.23	18.63
Untreated,	9.23	5.62	37.85	2.09	1.31	19.33
Acid phosphate,	9.88	6.37	39.20	2.10	1.28	20.79
Treatment (1931)						
South Area:						
Sodium nitrate,	18.65	14.12	43.09	2.61	1.48	48.59
Untreated,	17.10	14.78	46.27	2.79	1.50	47.77
Acid phosphate,	15.56	12.66	44.87	2.67	1.47	41.45
North Area:						
Sodium nitrate,	17.93	16.61	48.09	2.51	1.30	45.01
Untreated,	17.44	18.66	51.64	2.44	1.19	42.57
Acid phosphate,	17.64	17.41	49.67	2.40	1.30	45.47

indirectly through the size of the plant rather than through an increase in the set of fruit per raceme.

Greenhouse Investigations, 1929

In order to determine the relative values of nitrogen and phosphorus in affecting fruit set, an infertile was prepared by mixing potting soil with an equal volume of bank sand. Three groups of twenty-four, six inch pots were prepared. To the first, 0.5 grams of sodium nitrate per pot was added. The second group was untreated and the third group received an initial application of 2.5 grams of potassium acid phosphate per pot. Additional nitrate and phosphate solutions were added from time to time to the pots of groups one and three respectively. At the same time that nutrient solutions were added to the treated pots an equal volume of water was added to the controls.

The pots were seeded on January 2 and set in clay saucers on the south end of a center bench in a greenhouse maintained at a 70 - 75°F day temperature. After the seedlings emerged the stand was reduced to one per pot. On about February 10 racemes appeared on the plants and their development seemed normal on all plants for the first few days after which a pronounced bud drop was found to be occurring. This condition persisted almost forty days. Meanwhile the peduncles of the racemes continued to elongate, likewise the primordia at the nodes of the peduncle. Spurlike outgrowths, one-eighth to one-fourth of an inch resulted. Finally on March 20 racemes, especially on the plants of the nitrate and phosphate groups, exhibited buds approaching the flowering stage and eventually these did flower, and fruit was set by March 29.

After the set of a limited number of fruits the racemes relapsed into the flowerless state again until May 17 when flowering was resumed and more fruit set. Accompanying this second blooming period, new laterals, stems, and racemes were produced. After the development of this second crop of fruits the plants were harvested and the set of fruits recorded according to position on the racemes and the type of raceme. That set on the old (primary) racemes during the first blossoming period was designated by first-set, that set later as second-set. The new racemes produced at the time of the second flowering were termed secondary raceme.

From the data in Table XII it is apparent that nitrogen, as applied to this low-fertility soil, was most effective in inducing set of fruits on the primary racemes with the first blooming, and this was also true for the set on secondary racemes. The second set of fruits on the primary racemes was low probably because of the presence of fruit already set on these racemes. Except for the higher initial set on primary racemes on the phosphate group, little difference is found between

TABLE XII -- GROWTH, YIELD, AND SET OF FRUIT AS INFLUENCED BY NITROGEN AND PHOSPHORUS APPLICATIONS TO A LOW-FERTILITY SOIL.

Results (Greenhouse, January-June, 1929)	Sand-Soil Mixture.		
	Plus Nitrogen	Untreated	Plus Phosphorus
Set of fruits per plant on:			
1. Primary racemes:			
a. First set,	4.67	0.13	1.71
b. second set,	10.70	13.17	11.81
2. Secondary Racemes,	17.26	16.66	16.43
3. All Racemes,	32.63	29.96	29.95
Racemes per plant:			
1. Fruitful,	16.21	16.61	16.71
2. Unfruitful,	3.96	4.21	4.81
3. Total,	20.17	20.82	21.52
Percent unfruitful racemes,	19.63	20.42	22.35
Fruits Set per raceme,			
1. Fruitful only,	2.01	1.80	1.79
2. All racemes,	1.62	1.44	1.39
Mean position of set (nodes):			
1. Primary racemes,	9.17	8.64	8.50
2. Secondary racemes,	3.79	3.71	3.39

this and the untreated group.

<u>1931</u>. Plants of Henderson Bush were grown in clean sand in a greenhouse bench. The seeds planted January 1 were spaced 6.5 x 8.0 inches and the bench divided into three plots of eighty plants each. On January 18 all plots were given a complete nutrient solution containing $Ca(NO_3)_2$, $MgSO_4$ and KH_2PO_4. Subsequent applications were made at weekly intervals but in the case of plot number one (minus N.) $CaCl_2$ was substituted for $Ca(NO_3)_2$, and in plot number three (minus P.) KCl replaced the KH_2PO_4. These substitutions were made in the same molecular proportions.

Racemes were appearing on the plants by February 4, and with continued development failed to produce open flowers due to the constant abscission of buds. On March 7 the plants of all plots were still unfruitful and flowerless. At that time half of each plot was equipped with screens and given four extra hours of light daily with a 500 Watt electric bulb. Flowering began with the minus N plot on March 12, with the minus P. on March 14, and the NPK plot flowered for the first time March 17. Flowers appeared on the two halves of the plots the same day, but flowering was more uniformly initiated in the halves receiving additional light.

The extension of day length was probably not started soon enough to be of much benefit, and it was not taken in consideration in summarizing the results. The plants were harvested when the oldest pods began to turn yellow. Data were taken on yield of vegetation and fruit, and on set of fruit. (Table XIII).

It is evident that the deficiency of nitrogen in the nutrient solution had little effect on the fruitfulness of the plants, but it reduced the vegetative growth considerably. Examination of the roots disclosed an abundant development of nodules, although no effort had been made to assure inoculations. The nodules were localized to a great extent on those roots making contact with the bottom and sides of the bench. Apparently the high concentrations of nitrates applied to the complete and minus P. plots inhibited nodule formation since only a few nodules were found by examination of many of the root systems from these plots.

The absence of phosphorus in the nutrient solution affected both vegetative development and set of fruits in comparison to both the other treatments. With nitrogen and phosphorus both present in the solution, maximum weight of plants, weight of fruits, and set of fruit per plant resulted. It should be noted that this highest yield of fruits was produced by a larger and more vegetative plant with many racemes. This extremely vegetative condition resulted in a reduction in efficiency in fruit production in these plants below that for plants grown

TABLE XIII-- GROWTH, YIELD, AND SET OF FRUIT AS INFLUENCED BY A DEFICIENCY OF NITROGEN AND PHOSPHORUS IN THE CULTURE SOLUTION.

Results With Sand Cultures (Greenhouse January - May, 1931)	Nutrient Solution.		
	Minus Nitrogen	Complete	Minus Phosphorus
Data on Growth and Yield:			
1. Average weight of plant (gms)	13.85	34.36	13.32
2. Average weight of fruit (gms)	16.12	19.81	9.03
3. Racemes per plant, - - - - - -	11.45	15.41	10.11
4. Fruits per plant, - - - - - -	7.5	7.99	4.46
5. Weight of fruits / weight of plant, - - - - - - - - - - - -	1.16	0.58	0.68
6. Number of fruits / weight of plant, - - - - - - - - - - - -	0.55	0.23	0.34
Data on Racemes and Fruit Set:			
1. Fruitful racemes per plant,-	5.15	5.54	3.61
2. Unfruitful racemes per plant,	6.70	9.81	6.26
3. Percent unfruitful racemes,-	53.97	63.91	63.46
4. Fruits per raceme (fruitful only), - - - - - - - - - - - -	1.46	1.43	1.31
5. Fruits per raceme (all) - -	0.67	0.52	0.48
6. Number of seeds per fruit, -	2.14	1.90	2.00

without nitrogen or phosphorus in the nutrient solutions.

Therefore it appears that those plants of the minus N. group with a moderate supply of nitrogen furnished by symbiotic fixation were most fruitful in respect to set of fruits per raceme, set of seeds per pod, and were most efficient in fruit production. The extremely vegetative plants of the NPK plots, although producing the greatest number and weight of fruits were least efficient in fruit production and less fruitful than the minus N group with respect to set of fruits per raceme and set of seeds per fruit.

CHEMICAL COMPOSITION OF THE PLANT

Numerous studies have established correlations between the chemical compositions and the vegetative growth, flowering, and fruiting in plants. Other studies have shown that the chemical composition and therefore the vegetative and reproductive responses of plants can be varied by altering the supply of certain mineral nutrients. Wilton and Morris (25) report that a soil deficiency of nitrates increased the carbohydrate content of soybeans but due to an abundant development of nodules, the nitrogen content was not affected. Kraybill and Smith (11) indicate that phosphorus deficient tomato plants were high in soluble and total carbohydrates, high in soluble and total nitrogen, and low in insoluble nitrogen. MacGillivray (14) reports analyses similar to those of Kraybill and Smith adding that at times the starch content of these phosphorus starved plants was unusually low.

Because fruitfulness in plants is associated with chemical composition and because chemical composition varies with the mineral nutrition, plants for chemical analyses were sampled from the various treatments used in the problem with the idea that a relationship between chemical composition and fruitfulness or unfruitfulness could be established.

Methods

Sampling. Plants from the different fertilizer treatments, different planting dates, and two stages of development of the plant were sampled from the field. A first sampling was made at the time blossoming began, a second after flowering and fruiting had continued for ten or twelve days.

Five to twelve representative plants from each treatment were used and in preparation for sampling, were separated into stems (exclusive of woody basal part of stem) leaf blades, and peduncles of the racemes. These materials were finely cut, mixed and portions weighed out and preserved in alcohol. Stem samples of 50 - 100 grams and leaf samples of fifty grams were taken in duplicate. The peduncles of the racemes were segregated as immature, flowering, fruiting, and in some cases barren. In some instances the basal half was analyzed separately from the terminal half. The size of the peduncle samples varied, but with one or two exceptions was over twenty-five grams fresh weight.

Preservation of Samples. Immediately after the material was cut and weighed it was transferred to wide mouth Erlenmeyer flasks containing 0.2 or 0.3 grams of calcium carbonate. Sufficient boiling, 95 percent alcohol was added to the flask to bring the final concentration to 75 - 80 percent and the flasks were placed in a water bath, boiled for about five minutes and then removed and stoppered. A paraffin seal was applied after the flasks had cooled.

Preparation of Samples for Analysis. The preservative alcohol was poured through a fine mesh sieve in a funnel into a 250 or 500 cc. volumetric flask. This sieve permitted the fine calcium carbonate to pass into the flask but retained the plant residue. All plant residue was transferred to the sieve and the containing funnel and the storage flask washed with 80 percent alcohol. The washings were poured over the residue in the funnel. After draining a few moments the tissue was transferred to an evaporating dish and dried at 65 - 70°C. After drying, the residue was cooled in a dessicator, weighed and ground to pass through a sixty mesh sieve.

Carbohydrate and Nitrogen Analysis. Suitable aliquots of the residue were weighed out and extracted with a corresponding aliquot of the storage alcohol in the soxhlet apparatus. Analyses of starch, acid hydrolyzable substances and insoluble nitrogen were carried out on the extracted residues, while sugars and soluble nitrogen in the extract were determined. The methods used in the carbohydrate determinations were essentially the same as those employed by Boswell (3). The nitrogen determinations were made on water free residues by the Gunning-Kjeldahl method,modified to include nitrates.

Phosphorus. Total phosphorous was determined by a magnesium nitrate fusion method suggested by Dr. R. P.

Thomas of the Department of Soils. Corresponding aliquots of residue and storage alcohol were placed in 50 cc. porcelain crucibles and magnesium nitrate added. The alcohol was ignited and burned off before the burners were started under the crucibles. This made it unnecessary to remove the alcohol by drying in the oven and also burned out some organic matter, thereby aiding the subsequent fusion.

Presentation of Results.

Racemes. Three groups of racemes were selected from plants in the field. The first totally barren, the second had fruit set on the first two basal nodes, and the third had fruit set both at the base and the terminal. The fruits were about one-third mature. The peduncles of the racemes were divided into terminal and basal portions which were preserved separately. (Table XIV)

It is evident that the gradient of carbohydrates and nitrogen between the base and terminal of the raceme is similar to that found in plant stems. If a new metabolic gradient is created upon fruit setting, and available nitrogen is directed into the developing fruit as suggested by Murneek (19) we should expect to find less nitrogen in the barren terminal portions of these racemes with fruit set at the base than in the terminals of barren racemes. These analyses do not show this condition since the percentage of both soluble and insoluble nitrogen was

TABLE XIV -- CARBOHYDRATE AND NITROGEN ANALYSES OF RACEMES.*

Part of Raceme	Kind of Raceme	Percent Water	Free Reducing Substances	Sucrose	Total Sugars	Acid Hydrol-Sub.	Starch	Nitrogen.			Ratio: Starch/Nitrogen
								Soluble	In-soluble	Total	
Terminal Half of Peduncle.	Totally Barren	81.08	3.41	3.03	6.44	17.99	4.21	1.02	2.60	3.62	1.16
	Fruit at Base	80.81	2.32	4.90	7.25	16.36	6.13	1.43	2.97	4.40	1.40
	Fruit Terminal &Base	73.95	1.39	2.82	4.21	17.91	8.74	1.11	2.23	3.34	2.62
Basal Half of Peduncle.	Totally Barren	79.05	5.03	2.64	7.67	21.06	7.65	0.69	1.92	2.61	2.93
	Fruit at Base	76.75	3.33	3.27	6.60	25.69	12.11	0.88	2.02	2.90	4.17
	Fruit Terminal & Base	75.01	3.09	0.30	3.39	28.06	14.13	0.77	1.83	2.60	5.45

*Expressed as percent dry weight.

highest in the terminal half of these racemes with fruits set on the first two basal nodes. Thus it appears that at least, under the conditions that these racemes were produced, fruit set on only two nodes at the base did not create a deficiency of nitrogen in the terminal portion of the raceme. However when more fruits were set, some of which were distributed on the terminal half of the raceme, there was a reduction in the nitrogen content of both the terminal and basal regions of the raceme.

The percentage of total carbohydrates is somewhat variable but in general there is a reduction in the sugar content of the tissue in close proximity to developing fruits. The reverse is true for starch which is high in that part of the peduncle bearing fruit and thus giving a consistent trend in the starch / nitrogen ratio. It should not be assumed from this that the set of fruit is favored by a broad ratio since these analyses do not represent the composition of the peduncles at the time the fruits were set.

From these analyses it appears that the developing fruits are active in reducing the sugar content of the tissues directly associated with them and that where several fruits are set on a raceme it is possible that nitrogen may become a limiting factor but the set of fruit on the first two nodes only, was insufficient to reduce the nitrogen content of the peduncle below that of a raceme devoid of of fruit.

Greenhouse Study, 1929. The plants used in this study were seeded in a greenhouse bench on January 2, in conjunction with those seeded in pots in the fertilizer study. In general the growth and the flowering responses were the same. However at the time the second flowering period was initiated (May 20) some irregularity was noted. Thus on May 25 some plants were well supplied with flowers, others were flowerless. Samples of stems of the flowering and flowerless plants were taken along with comparable samples of flowering and flowerless racemes. The flowering racemes were as an average younger than those not flowering. (Table XV)

The difference in the composition of the two types of plants and racemes is not outstanding since the flowerless plants were approaching the flowering condition, while the stems of these flowering plants contained less total carbohydrates, the proportion of carbohydrates to nitrogen is greater. A high starch content is associated with flowering in both stems and racemes. All carbohydrate fractions were higher in the flowering racemes in spite of the fact that they were less mature and contained more nitrogen.

The results of these carbohydrate and nitrogen analyses suggest that the advent of flowering in these racemes was associated with an increase in the carbohydrate content. In both stems and racemes a greater ratio of carbohydrates to nitrogen was found associated with flowering.

TABLE XV -- RELATION OF CHEMICAL COMPOSITION TO THE ADVENT OF FLOWERING

(GREENHOUSE - 1929)

Part of Plant Kind of Plant	Percent Water	Free Reducing Sugars	Sucrose	Total Sugars	Acid Hydrolzable Substances	Starch	Nitrogen			Ratio: Starch/Nitrogen
							Soluble	In-soluble	Total	
Plant Stems:										
Flowering:	79.45	5.05	2.21	7.26	32.35	19.65	1.33	1.81	3.14	6.26
Flowerless:	80.77	4.95	3.03	7.98	33.36	17.91	1.49	1.79	3.28	5.46
Peduncle of Raceme:										
Flowering:	81.01	4.40	2.52	6.93	22.72	11.23	2.35	2.66	5.01	2.24
Flowerless:	82.29	4.37	1.57	5.94	20.05	9.58	1.98	2.94	4.92	1.95

Table XVI COMPOSITION OF PLANTS AS AFFECTED BY DEFICIENCIES OF NITROGEN AND PHOSPHORUS IN THE CULTURE SOLUTION

(GREENHOUSE - 1931)

Part of Plant: Nutrient Solution:	Percent Water	Free Reducing Sugars	Sucrose	Total Sugars	Acid Hydrolzable Substances	Starch	Nitrogen:			Ratio: Starch/Nitrogen	Total Phosphorus
							Soluble	In-soluble	Total		
Stems:											
Minus N - - -	70.26	4.24	3.47	7.71	43.32	20.49	0.53	0.98	1.51	13.58	.428
N. P. K.- - -	79.69	5.75	4.11	9.84	31.65	14.36	1.16	1.24	2.40	5.98	.457
Minus P.- - -	75.83	3.13	3.09	6.22	45.14	22.76	1.20	1.00	2.20	10.36	
Leaves:											
Minus N.- - -	82.35	3.35	2.58	5.93	16.78	9.04	0.53	3.58	4.08	2.22	.475
N. P. K.- - -	82.62	3.59	1.97	5.56	11.48	5.71	0.61	3.98	4.59	1.24	.438
Minus P.- - -	82.05	2.16	1.82	3.98	11.11	6.21	0.52	3.41	3.98	1.59	.282

Greenhouse, 1931. Plants of three groups grown in the greenhouse in 1931 were samples on March 16. The Minus N. group had been flowering for four days. Some of the plants of the Minus P. group had just started and those of the N.P.K. group were still without flowers. Plants well set with flowers were selected from the first, along with flowerless plants of the other two groups. Samples of stems and leaves were secured and the carbohydrate fractions soluble and insoluble nitrogen, and total phosphorus estimated. (Table XVI).

The analyses are comparable to those secured from greenhouse plants in 1929 in that flowering was associated with a high ratio of carbohydrates to nitrogen. The order in which blooming began corresponded to the starch/nitrogen or total carbohydrate / nitrogen ratios. In the case of the stems it was the increased nitrogen content of the minus phosphorus plants which lowered the ratio, carbohydrate being about equal to that of the Minus N. plants. Contrary to MaGillivray's work on P. difficiency in the tomato, the soluble-carbohydrate content is low for both stems and leaves in these phosphorus deficient bean plants, while in the stems the insoluble carbohydrates even exceed that found in the stems of the Minus N. plants. Comparing the nitrogen content of the stems of the phosphorus deficient plants with that of the N.P.K. plants it appears that the lack of phosphorus has limited the intake of nitrogen. However if the percentages were expressed on a fresh weight basis, total nitrogen would be highest for the minus P. stems. The low content of insoluble nitrogen is in agreement with the prevalent conception that an inadequacy of phosphorous limits the elaboration of nitrogen.

<u>Field, 1929</u>. Plants of the May 24 planting were sampled from the fertilizer plots on August 13 at a time when the fruits were about two-thirds mature. At the time the plants of the phosphate plot appeared most mature with little or no recent vegetative growth. Those of the nitrate plot seemed less mature, more vigorous with some new growth. Samples of stems, racemes, and leaf blades were taken. The peduncles of the racemes were divided into terminal and basal halves. Most of the fruit was set at the base of the racemes.

The analyses in Table XVII indicate that the carbohydrate content of the plants in a more mature state of development was not affected much by the fertilizer treatments. The nitrogen content of the various parts of the plants receiving nitrate was slightly higher than the corresponding part for the other plants. The total nitrogen content for the stems and peduncles was lowest for plants from the phosphate plot and a high ratio of carbohydrates to nitrogen resulted. Whether or not this difference in composition is related to the decreased

TABLE XVII -- CARBOHYDRATE AND NITROGEN ANALYSES OF VARIOUS PARTS OF PLANT IN RELATION TO FERTILIZER TREATMENT. (FIELD 1929)

	Plant Part	Treatment	Per-cent H_2O	Free Red Sub.	Sucrose	Total Sugar	Starch	AH	Sol. N	Insol. N	Total N	Ratio Starch / Total N.
	Stems	Nitrate	79.69	2.63	1.92	4.55	7.33	21.69	1.200	1.160	2.36	3.105
		Untreated	80.64	2.04	1.64	3.68	5.47	20.46	1.068	1.141	2.209	2.476
Planted		Phosphate	80.78	1.96	1.51	3.47	4.81	19.62	1.081	0.984	2.065	2.318
May 24	Base of Peduncle	Nitrate	78.00	1.72	1.82	3.54	4.21	19.37	1.362	1.417	2.779	1.515
		Untreated	78.93	1.20	1.83	3.03	4.13	20.71	1.265	1.387	2.652	1.557
		Phosphate	79.04	1.22	1Y41	2.63	3.99	19.79	0.996	1.226	2.222	1.796
Sampled	Terminal Of Peduncle	Nitrate	80.24	1.20	1.55	2.75	3.87	15.94	2.379	2.369	4.748	0.813
		Untreated	81.49	1.24	1.50	2.74	2.80	16.01	2.159	2.241	4.400	0.637
Aug.13		Phosphate	82.08	1.11	2.30	3.41	3.19	14.43	1.937	2.229	4.166	0.766
	Leaf Blade	Nitrate	78.03	0.53	1.96	2.49	4.12	9.49	0.412	3.752	4.164	0.989
(81		Untreated	78.07	0.51	1.83	2.34	4.08	9.01	0.232	3.442	3.674	1.112
days)		Phosphate	78.42	0.64	1.82	2.46	3.31	10.95	0.282	3.733	4.015	0.825

vegetative growth and yield of fruits of the plants of this plot is questionable, because of the stage of development at which the plants were sampled.

Field 1930-1931. Plants of the fertilizer plots and representing four of the ten dates of planting groups were sampled at the flowering and fruiting stages of development. Principally stems were analyzed. Tables XVIII and XIX contain the carbohydrate and nitrogen analyses of plants grown in 1930. Little or no relationship is found between the chemical composition of the plant stems and the set of fruits per raceme or percent of unfruitful racemes. As in 1929 the nitrogen content is somewhat low for the plants of the acid phosphate plots for the plantings of May 10 and May 24, corresponding to a low yield of fruits per plant for the treatment on the south area.

The carbohydrate and nitrogen analyses of stems of plants grown in 1931, presented in Tables XX and XXI show even less variation with time of planting or with fertilizer treatment than in 1931. This was contrary to what was expected. With an abundance of moisture and some differences in growth it was anticipated that chemical differences would be found in these plants. Generally the carbohydrate content is lower and the nitrogen content higher in the stems of the plants sampled in 1931 than in those sampled in 1930.

TABLE XVIII- CARBOHYDRATE ANALYSES OF PLANT STEMS -- 1930

(Expressed as Percent of Dry Weight)

Age of Plants. Time of Seeding.	Fertilizer Treatment.	Free Reducing Sugars	Sucrose	Total Sugars	Acid Hydrolyzable Substances.	Starch
Flowering Stage. May 10,	Nitrate	5.81	2.68	8.49	21.85	7.52
	Untreated	6.24	3.01	9.25	22.94	8.79
	Phosphate	7.68	2.76	10.44	22.83	8.86
May 31,	Nitrate	7.58	2.17	9.75	24.29	9.50
	Untreated	7.87	3.16	11.03	23.44	8.63
	Phosphate	2.46	3.02	10.48	24.98	9.39
June 21,	Nitrate	9.54	2.71	12.25	23.64	9.33
	Untreated	8.65	3.81	12.46	24.41	10.16
	Phosphate	8.85	3.72	12.57	24.05	9.63
Fruiting Stage. May 10,	Nitrate	7.21	1.93	9.14	25.27	10.25
	Untreated	7.57	2.05	9.62	26.04	9.48
	Phosphate	6.54	0.36	6.90	27.73	10.17
May 31,	Nitrate	6.35	2.88	9.23	29.48	14.73
	Untreated	6.12	2.86	8.98	29.09	14.30
	Phosphate	6.32	3.26	9.58	28.69	13.00
June 21,	Nitrate	6.95	2.47	9.42	30.67	14.40
	Untreated	6.33	2.69	9.02	30.76	16.45
	Phosphate	6.78	2.95	9.73	31.82	17.50
July 12,	Nitrate	7.18	2.20	9.38	33.35	16.29
	Untreated	5.86	3.24	9.10	29.04	15.90
	Phosphate	5.49	3.35	8.84	31.37	17.49

TABLE XIX -- NITROGEN ANALYSES OF PLANT STEM -- 1930.

(Expressed as Percent Dry Weight)

Age of Plants. Time of Seeding.	Fertilizer Treatment.	Percent Water	Nitrogen			Ratio: $\frac{\text{Carbohydrates}}{\text{Nitrogen}}$
			Soluble	Insoluble	Total	
Flowering Stage. May 10,	Nitrate	80.28	1.11	1.47	2.58	11.73
	Untreated	81.78	1.08	1.63	2.71	12.25
	Phosphate	81.86	0.99	1.50	2.49	13.45
May 31,	Nitrate	79.42	0.93	1.31	2.24	15.17
	Untreated	80.46	0.95	1.32	2.27	15.13
	Phosphate	78.89	0.81	1.26	2.07	17.15
June 21,	Nitrate	78.85	0.89	1.32	2.21	16.93
	Untreated	77.87	0.92	1.27	2.19	16.85
	Phosphate	78.24	0.84	1.33	2.17	16.90
Fruiting Stage. May 10,	Nitrate	79.09	0.90	1.36	2.26	15.20
	Untreated	78.48	0.87	1.21	2.08	17.11
	Phosphate	77.84	0.83	1.07	1.90	18.24
May 31,	Nitrate	76.02	0.86	1.04	1.90	20.45
	Untreated	75.74	0.89	1.04	1.93	19.73
	Phosphate	77.08	0.80	0.99	1.79	21.48
June 21st,	Nitrate	74.09	0.61	1.51	2.12	18.91
	Untreated	74.24	0.91	1.30	2.21	17.95
	Phosphate	74.21	0.75	1.48	2.23	18.64
July 12,	Nitrate	76.00	0.86	1.14	2.00	20.80
	Untreated	75.89	1.07	1.37	2.44	15.63
	Phosphate	75.60	1.05	1.21	2.26	17.75

TABLE XX -- CARBOHYDRATE ANALYSES OF PLANT STEMS -- 1931

(Expressed as Percent Dry Weight)

Age of Plants. Time of Seeding.	Fertilizer Treatment	Free Reducing Sugars	Sucrose	Total Sugars	Acid Hydrolyzable Substances	Starch
Flowering Stage, May 18,	Nitrate	5.45	2.63	8.08	17.83	3.89
	Untreated	5.04	2.73	7.77	17.98	3.91
	Phosphate	5.19	3.00	8.19	17.98	3.94
June 2,	Nitrate	6.28	2.63	8.91	18.31	4.82
	Untreated	6.59	2.88	9.47	18.75	4.17
	Phosphate	6.52	2.95	9.47	18.64	5.45
July 13,	Nitrate	5.05	3.40	8.45	18.44	4.20
	Untreated	6.16	3.65	9.82	18.11	3.58
	Phosphate	5.42	3.54	8.96	18.23	3.79
Fruiting Stage, May 18,	Nitrate	4.58	1.92	6.50	19.37	6.05
	Untreated	5.70	2.06	7.75	18.76	5.03
	Phosphate	5.42	1.94	7.36	18.88	5.83
June 2,	Nitrate	4.50	1.57	6.07	18.14	5.38
	Untreated	4.35	1.72	6.07	19.20	5.86
	Phosphate	5.44	1.99	7.43	19.81	6.70
June 22,	Nitrate	5.25	3.31	8.56	22.69	9.09
	Untreated	3.98	4.54	8.22	24.86	9.57
	Phosphate	3.91	4.49	8.39	25.29	8.90
July 13,	Nitrate	5.55	2.10	7.64	26.34	10.25
	Untreated	5.93	2.74	8.67	25.17	9.86
	Phosphate	5.12	2.66	7.78	26.08	9.88

TABLE XXI -- NITROGEN ANALYSES OF PLANT STEM -- 1931

(Expressed as Percent Dry Weight)

Age of Plants. Time of Seeding.	Fertilizer Treatment.	Percent Water	Nitrogen			Ratio: Carbohydrates / Nitrogen
			Soluble	Insoluble	Total	
Flowering Stage. May 18,	Nitrate	84.5	1.47	1.55	3.02	8.52
	Untreated	85.0	1.47	1.70	3.18	8.10
	Phosphate	84.3	1.25	1.74	2.99	8.77
June 2,	Nitrate	85.1	1.10	1.80	2.90	9.37
	Untreated	84.8	1.17	1.59	2.77	10.20
	Phosphate	84.1	1.16	1.74	2.91	9.68
July 13,	Nitrate	85.1	1.43	1.64	3.07	8.76
	Untreated	85.4	1.22	1.77	2.99	9.34
	Phosphate	85.4	1.20	1.79	2.99	8.95
Fruiting Stage. May 18,	Nitrate	82.5	1.47	1.47	2.94	9.19
	Untreated	83.8	1.41	1.64	3.05	8.69
	Phosphate	83.7	1.31	1.43	2.74	9.59
June 2,	Nitrate	82.2	1.60	1.49	3.09	7.84
	Untreated	82.4	1.52	1.43	2.95	8.57
	Phosphate	81.9	1.26	1.42	2.68	10.09
June 22,	Nitrate	81.0	1.22	1.31	2.53	10.35
	Untreated	80.1	1.13	1.18	2.31	14.64
	Phosphate	80.9	1.22	1.27	2.49	13.49
July 13,	Nitrate	80.7	1.01	1.31	2.32	14.64
	Untreated	81.4	0.99	1.39	2.38	14.22
	Phosphate	80.9	1.01	1.31	2.32	14.56

Total phosphorus was determined on material sampled in 1931 from the plantings of May 18 and July 13 (Table XXII) Generally the phosphorous content was higher for the latter planting and was also high for the younger tissues, but no consistent increase occurred in phosphorus content of the tissues of those plants treated with acid phosphate.

TABLE XXII -- TOTAL PHOSPHORUS CONTENT OF DIFFERENT TISSUES AS INFLUENCED BY FERTILIZER TREATMENT, STAGE OF DEVELOPMENT OF PLANT AND DATE OF PLANTING

Part of Plant Analyzed: Fertilizer Treatment: (Field 1931)	Date Planted – Stage of Development			
	Flowering		Fruiting	
	May 18	July 13	May 18	July 13
Stems of Plants:				
Nitrate,	.386	.401	.324	.329
Untreated,	.431	.432	.341	.342
Phosphate,	.412	.464	.334	.357
Leaves:				
Nitrate,	.359	.388	.296	.348
Untreated,	.290	.388	.305	.352
Phosphate,	.368	.376	.316	—
Peduncles of Racemes:				
A. Flowering,				
Nitrate,	.409	.540	.343	.445
Untreated,	.438	.510	.401	.381
Phosphate,	.425	.558	.421	.460
B. Fruiting,				
Nitrate,			.330	.435
Untreated,			.364	.434
Phosphate,			.316	.515

RELATION OF SET OF FRUITS PER RACEME TO SET OF SEEDS PER POD

Henderson Bush Lima beans usually produce four ovules to the pod although at times fruits with only three, and infrequently those with five ovules are found. Mature fruits commonly show some ovule abortion, varying from flat parthenocarpic pods to those with all ovules developed. Pods with two and three seeds are most numerous.

Because the fruitfulness of the plants, as expressed by the number of fruits per raceme tended to vary, it was supposed that this same variation might occur in the set or maturation of seeds in the pod. Therefore in 1930 beginning with the June 14 planting, a composite sample of about one-hundred fruits was secured from each of the twelve plots representing that particular planting date and the number of developed ovules determined by examining the fruits in a strong beam of light in much the same way that eggs are candled.

Similar data on the set of seeds per fruit were secured from the remainder of the plantings that year and also from fruits on the plants in the buffer rows which were planted May 10. In 1931 data on the set of seeds were secured for all plantings. The number of parthenocarpic fruits at harvest was recorded, but since many of these were lost from the plants prior to harvest, the total number of pods set could not be included in the computation of the averages.

The data in Table XXIII are somewhat fragmentary for 1930, but there is some indication that the number of seeds per fruit varies directly with the number of fruits set on the raceme. This same relationship was found again in 1931. The coefficient of correlation for the set of fruit per raceme with the set of seeds in the pod was found to be +.511 ±.08 for the latter year.

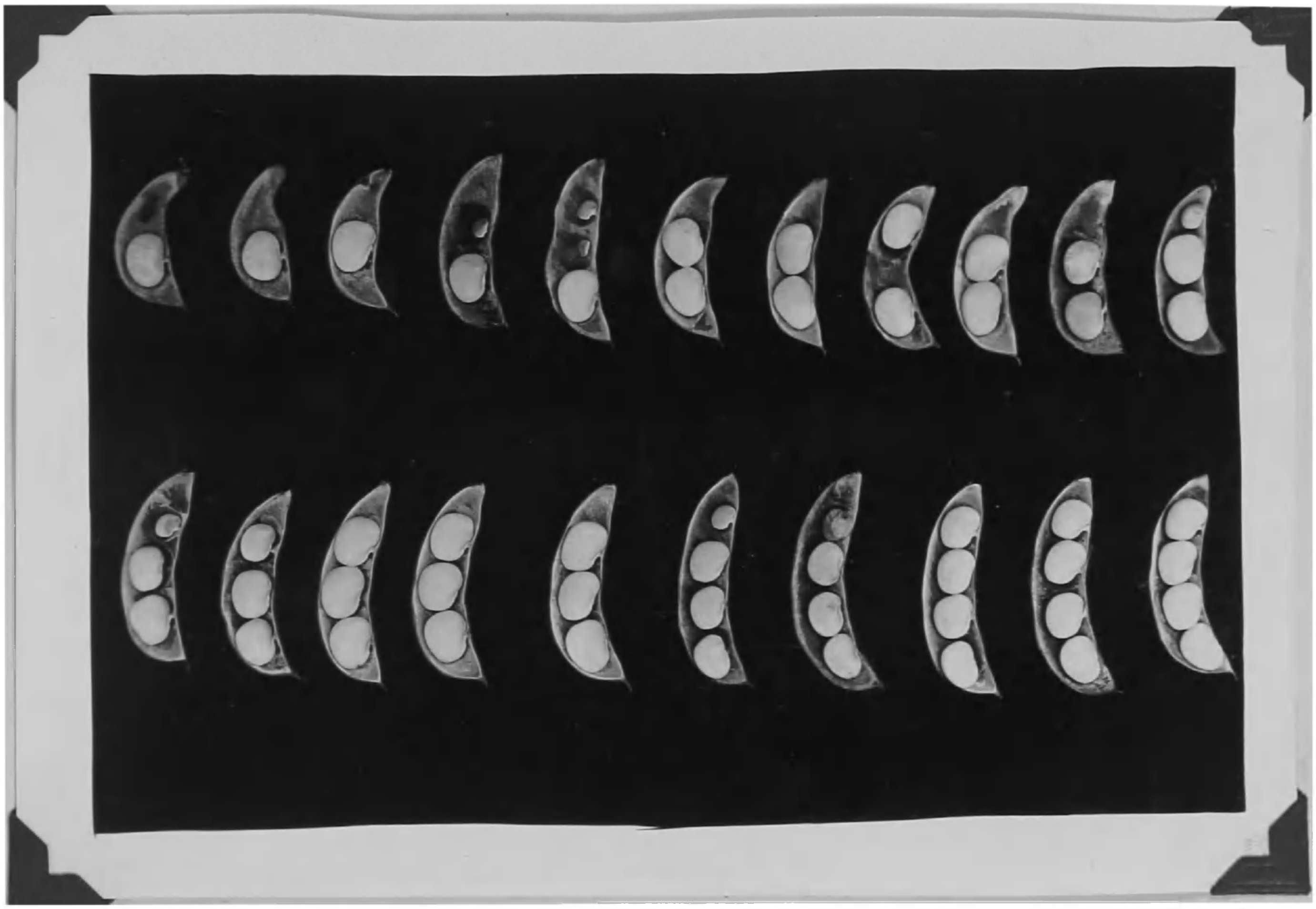

Figure XII — The number of seeds developed in the pod is variable. Ovule abortion is most frequent at the stem end.

When recording the data on number of seeds per pod in 1930, it was observed that ovule abortion most frequently occurred at the stem end (See Figure XII) and in many cases a gradient in size of seed extended from this end to the stylar end of the fruit. Not only was the number of developed ovules recorded, but also the number and position of those distinctly aborted. The pods were opened when the undeveloped ovule could not be discerned by external observation. Because some fruits produce but three ovules only three positions are designated in the summary of the data. Thus position one is represented by the ovule in the stem end of the pod, position two by the middle ovule of a three ovuled pod and the two middle ovules in a four ovuled pod, while position three is represented by the ovule in the stylar end of the pod.

In Table XXIV the results are presented in two ways. In the first three colums the extent of the abortion for the three respective positions is expressed as percent of the total number of ovule that failed to develop. From this we are able to see just how much the ovules in the different positions contribute to the total abortion within the pod. In all cases there were more undeveloped ovules in the position at the stem end, as an average over fifty percent. Furthermore it is apparent that for those plantings where the set of fruits per raceme and set of seeds per fruit were at a minimum (Table XXII) the total of the aborted ovules is shared more by the intermediate position in the pod.

The three columns at the right represent the percent of the ovules that failed to develop based on the total number of ovules initiated in each position. This shows that regardless of variations in the number of ovules set in the pod as a whole, the fertility of those at the stem end remained at a low but fairly constant level. Thus the set of ovules in the intermediate position varied more in relation to the set of fruit on the raceme. It seems that the position at the stem end of the pod is more or less disadvantageous under all conditions.

The fact that fertility decreases directly with the distance from style to ovule suggests that slow pollen tube growth is a potent factor associated with ovule abortion. Furthermore it is suggested that the vigor of the pollen varies in relation to temperature and humidity since a relationship has been established between these factors and set of fruits per raceme (see time of planting study) and since the number of developed seeds is postively correlated with the set of fruits per raceme. The conclusion that pollen vigor is affected by temperature and humidity is further substantiated by the data in Table XXIII where it is shown that ovule abortion was increased even in positions near the stylar end of the pod when pollination occurred under adverse external conditions.

TABLE XXIII.- RELATION OF NUMBER OF SEEDS PER POD TO SET OF FRUITS PER RACEME.

Planting Date 1930	Planting Date 1931	1930 Seeds per Pod	1930 Fruits per Raceme	1931 Seeds per Pod	1931 Fruits per Raceme
May 10	May 11	2.42		2.57	2.25
May 17	May 18		3.24	2.55	2.47
May 24	May 25		2.73	2.54	2.42
May 31	June 2		2.43	2.59	2.68
June 7	June 8		2.21	2.58	2.57
June 14	June 15	2.19	2.33	2.49	2.41
June 7	June 8		2.18	2.53	2.61
June 14	June 15	1.95	2.15	2.48	2.42
June 21	June 22	2.11	1.94	2.43	2.24
June 28	June 29	2.25	2.25	2.47	2.21
July 5	July 6	2.36	2.03	2.44	2.17
July 12	July 13	2.22	2.07	2.50	2.30
Average		2.21	2.32	2.51	2.40

TABLE XXIV -- POSITION OF ABORTED OVULES IN THE POD.

Date Planted (1930)	Percent Aborted Based on: Total Ovules Aborted. (1) Stem end	(2) Middle	(3) Stylar End	Total Ovules Produced. (1) Stem end	(2) Middle	(3) Stylar End
	Percent	Percent	Percent	Percent	Percent	Percent
May 10	66.44	23.36	15.18	39.50	15.00	9.75
June 14	48.98	33.12	17.94	55.43	34.73	20.31
June 21	42.06	40.91	17.06	38.89	35.57	15.78
June 28	43.25	40.77	15.40	36.24	31.01	12.87
July 5	50.00	38.92	11.07	38.68	26.27	8.55
July 12	52.23	34.35	13.39	40.58	24.28	10.38

HISTOLOGICAL STUDIES OF STAMENS AND PISTILS IN RELATION TO DROP

The data and observations presented thus far have indicated that the set of fruit in Lima beans is affected by external factors such as temperature and humidity, by complex internal or nutritional conditions arising from vegetative and fruit development, but did not preclude the possibility of a reduction in the set resulting from the degeneration of the reproductive structures. Such degeneration might arise as a direct result of nutrition or as a result of an evolutionary tendency in this plant.

Specimens of buds in various stages of development, open flowers and small fruits were gathered at times during the course of this study. Abscissed structures along with seemingly normal ones were collected on the same day. These materials were placed in medium chromo-acetic killing solution for twenty-four hours, washed an equal time in running water, and prepared for sectioning by the paraffin method. Sections were cut in series, six to ten microns in thickness. Several stains were used including Delafields haematoxylin, Haidenhain's iron-alum haemotoxylin, safranin-light green combination and Flemming's tripe stain.

Microscopic observations made with a great number of sectioned buds and flowers failed to disclose any striking abnormalities in the development of the pollen or embryo sacs. Those deviations from the normal which were found apparently were not correlated with any definite stage in the development of these organs. Furthermore degeneration occurred with almost equal regularity in the apparently normal and abscissed buds and flowers.

Some abscissed structures were found which displayed complete degeneration of both the reproductive and the associated tissues but it is likely that degeneration in these cases was the result of abscission rather than the cause. This seems probable in view of the fact that in some cases, degeneration was found in the absence of abscission.

In general pollen degeneration occurred more frequently than degeneration of the embryo sac, and at times may have been the result of unfavorable weather, but usually sufficient plump grains were present to effect fertilization assuming that they were functional.

Ovules partially developed before aborting contained embryo exhibiting various degrees of disintergration. On the other hand ovules in small abscissed fruits frequently appeared normal in development.

CONCLUSIONS

The data obtained in these investigations, extending over a period of four years indicate that the total yield of fruits in Henderson Bush Lima bean was affected most by the size of the plant and the total bearing area as expressed in raceme per plant.

The rate of development or maturation was determined to a large extent by temperature, but the ultimate size of the plant varied more in relation to the moisture supply (as related to precipitation) than in relation to temperature.

In a comparison of determinate and indeterminate racemes the former in a terminal position were found to be more favorably situated on the plant and contributed more to its yield of fruits.

Blossoming is initiated first at the base of the racemes and progresses to the terminal. A second and possibly a third cycle of blossoms may follow.

Fruit setting normally occurs with greatest frequency on the basal node and decreases in frequency in proportion to the distance from the base of the raceme. Adverse weather and light conditions at times, were instrumental in preventing fruit set for the first few days of blossoming. When these periods were brief fruit setting occurred later after the flowering wave had advanced toward the terminal of the raceme.

A great excess of reproductive structure was found to be produced in the inflorescences of the variety used in this study. These excess structures by necessity are lost by abscission. Dropping is common to all early stage of development and over ninety percent of these structures may absciss without seriously lowering the yield of fruits.

The daily drop rate of buds, flowers, and fruits increased during the latter part of the blossoming life of the raceme when flowering was confined mostly to the terminal region and after fruit had set below. It appeared that the drop increase is caused by an inherent lack of vigor in the terminal region of the raceme and the monopoly of food supplies by fruit developing at a lower position.

Irregular fluctuations were found to occur in this daily drop trend which apparently were associated with temperature and possibly humidity. The set of fruits per fruitful raceme, although varying much less than the set of fruits per plant, for plants grown at different times of the year, did exhibit deviations which apparently were associated with the mean temperature and relative humidity of the blossoming period. Temperature and humidity seemed to be inter-related factors in affecting the set of fruit. A high temperature / humidity ratio was found to be associated with a low set of fruits.

The long blooming period for racemes of the Henderson Bush variety is a fairly effective protection against brief periods of adverse weather as related to fruit setting.

An excessive nitrogen supply and a deficiency of phosphorus both reduced the set of fruits per raceme under greenhouse conditions. Applications of available nitrogen and phosphorus to plants in the field increased vegetative development and yield of fruits rather inconsistently but had little affect on the set of fruits per raceme.

Chemical analysis of stems and raceme peduncles indicated that the advent of flowering was associated with a fairly high carbohydrate content or a high proportion of carbohydrates to nitrogen. The carbohydrate and nitrogen contents at the time flowering began in plants under field conditions were almost constant regardless of the time of the year or fertilizers applied. A greater accumulation of carbohydrates occurred prior to flowering in plants when blossoming was delayed by unfavorable day length in the greenhouse. Little if any relationship was found between the chemical composition of the plant and the set of fruit under field conditions.

The number of seeds produced in the pods was postively correlated with the set of fruits per raceme. The unusually high percentage of ovule abortions occurring in the position at the stem end of the fruit and the tendency for abortion to increase in the mid-section of the pod with more adverse weather suggested that slow pollen tube growth is responsible for at least a part of the degenerate ovules and that the vigor of the pollen is affected by external factors.

Microscopic examination of numerous buds, flowers, and ovules failed to reveal any consistent abnormality which might account entirely for the dropping of flowers or immature fruits. In general degeneration was more frequent in miscrospores than in megaspores of buds and blossoms. It appeared that this degeneration was associated to some extent with weather conditions.

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