

AN ABSTRACT OF THE THESIS OF

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Title QUANTITATIVE INHERITANCE OF GROWTH HABIT IN THE  
BUSH BEAN, PHASEOLUS VULGARIS L.

Abstract approved \_\_\_\_\_  
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Analysis of the gene action involved in the expression of growth habit and some morphological characters related to habit was undertaken for bush beans grown in several environments.

During 1961 and 1962, comparison of true bush bean varieties with bush varieties derived from backcrossing to the Blue Lake FM-1 pole bean demonstrated the greater general sensitivity of the derived bushes to environmental change imposed by different times of planting, in-row plant spacings, locations, and by short periods of imposed shade. As compared to true bush varieties, derived bush varieties exhibited markedly greater stem elongation under winter greenhouse conditions and, in the field, to closer spacing, later planting, and shade. In all varieties the number of central stem internodes was not greatly sensitive to environmental change.

Two true bush varieties (White Seeded Tendercrop and

Puregold Wax) and two derived bush varieties (OSU 836-9 and OSU 2466) were used as a population of four parents among which the 12 possible crosses were made. Evaluation of the parents and  $F_1$  progeny in the greenhouse and of the parents and  $F_1$  and  $F_2$  progeny at two- and six-inch in-row plant spacings in both a mid-May and a late June field planting in 1962 was made for growth habit and several morphological characters related to habit. Except for height of plant, measured shortly prior to anthesis, all characters were measured or rated at the time of pod maturity for processing.

In the greenhouse true bush varieties appeared to contain more of the recessive alleles for growth habit, plant height, length, mean internode length, number of central stem internodes, and number of branches. Over the field environments the tendency toward recessiveness in true bush varieties, while evident for growth habit and number of central stem internodes, was somewhat less evident for plant height, length, mean internode length and number of branches.

In all environments the net effect of the genes conditioning the expression of gross habit of growth, pod placement, and number of central stem internodes was largely additive. Conversely, in the expression of plant length, height, and mean internode length the net effect was largely a non-additive one; in all environments marked heterosis (as measured by departure of the  $F_1$  beyond the

range of the parents) was seen for these three characters. A tendency for heterosis in number of branches under field conditions was reversed to a tendency for negative heterosis under winter conditions in the greenhouse.

Reciprocal differences were noted under winter greenhouse conditions for plant height, length, and mean internode length in  $F_1$  progeny of crosses between OSU 2466 and White Seeded Tendercrop.

During the winter season, selection in the greenhouse probably is effective for growth habit and related characters. Although the character, plant height, is greatly modified by environment and shows heterotic response in crosses between true and derived bush varieties, selection in the greenhouse among small  $F_3$  families from crosses between White Seeded Tendercrop and various derived bush varieties was shown to be effective.

Association between pod color (wax versus green) and growth habit, plant length, height, internode length, and number of branches was demonstrated in the  $F_2$  families derived from Puregold Wax. Generally, the presence of these associations was more highly probable in the  $F_2$  families derived from Puregold Wax crossed with White Seeded Tendercrop than with OSU 836-9 or OSU 2466. Wax segregates tended to resemble Puregold Wax in possessing more branches and shorter height, length, and internode length.

QUANTITATIVE INHERITANCE OF GROWTH HABIT  
IN THE BUSH BEAN, PHASEOLUS VULGARIS L.

by

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QUANTITATIVE INHERITANCE OF GROWTH HABIT  
IN THE BUSH BEAN, PHASEOLUS VULGARIS L.

INTRODUCTION

The snap bean industry in Oregon continues to increase its contribution toward state and national agricultural income. In 1962 production on the more than 16,000 acres grown was valued in excess of 13 million dollars and represented more than 28 percent of the total value of snap beans for processing produced in the United States. Oregon now ranks first among the states in production and in total value of snap beans produced for processing.

Unlike other major production areas, Oregon and her neighboring states in the Pacific Northwest have based the industry almost entirely on pole varieties. The favorable environmental conditions found in this area--for high yields of good quality--together with the inherently superior pod quality of Blue Lake pole varieties have provided sufficient competitive advantage in a high cost industry to permit gradual expansion of acreage. Costs arising from trellis construction, irrigation, hand harvesting, and the greater distance from markets have been outweighed by higher yields of a more desirable product than can be produced from pole or bush varieties in competing areas.

Increased labor and material costs together with (1) some

improvement in pod quality of bush varieties grown in eastern and midwestern processing areas, and (2) the development of satisfactory bush bean harvesters, have partially overcome this competitive advantage. The need for locally adapted, high yielding bush varieties possessing Blue Lake pod quality and having a sturdy upright habit of growth, facilitating mechanical harvesting, has long been apparent. A survey of snap bean processors in 1962 revealed that the industry in Oregon considers further breeding work with bush type Blue Lake varieties second in priority among 47 bean research problems.

Beginning in 1951, outcrosses of the Blue Lake pole types to bush varieties were made by Dr. W.A. Frazier at the Oregon Agricultural Experiment Station. A backcross program using rigidly selected, determinate  $F_2$  plants and the FM-1 pole variety as a recurrent parent, was adopted to transfer the superior pod quality of the pole bean parent to bush beans. Although pod quality had improved sufficiently after five to six backcrosses, the desirable growth habit of the non-recurrent parent had been lost. At maturity plants were prostrate and sprawling. Even though considerable diversity in growth habit existed among these Blue Lake "derived bushes", outcrosses to "true bushes" appeared necessary if acceptable growth habit was to be obtained.

Interest has been expressed in the genetic basis of habit

differences separating derived from true bushes. In most breeding programs some understanding of the mode of inheritance of the character(s) under consideration is imperative. The complex inheritance patterns so often implied in breeding studies of such characters as growth habit usually appear to involve many genes. Increasing numbers of pertinent loci enhance the likelihood of linkage, interallelic interactions, multiple alleles at some loci, and other complicating phenomena. Nevertheless, it should be possible to ascertain the net effect of all pertinent loci taken as a whole and thus to arrive at an estimation of the inheritance pattern.

It is equally necessary that one appreciate the impact of environment upon character expression. Differential response of lines within a population may drastically alter selection efficiency. The plasticity of the bean plant to environmental influence has long been recognized and general comparisons of behavior of true and derived bushes have indicated that strong genotype  $\times$  environmental interactions for growth habit may exist.

The present study was undertaken to examine, over a range of environments, the inheritance of (1) growth habit, and (2) some of the morphological characters which contribute to habit and which further serve to distinguish habit types in the bush bean. This investigation will provide a more complete understanding

of growth habit expression through (1) postulation of the gene action involved in character expression, (2) correlation of characters contributing to habit, and (3) illustration of environmental influence on character expression.

## REVIEW OF LITERATURE

### Growth Habit, A Complex Character

According to Norton (15, p. 547-561) habit represents the external form of the plant taken as a whole and is the combined result of many independent characters. Morphological characters such as (1) length of axis, (2) axial or terminal inflorescence (3) degree of twining, (4) amount and degree of branching, (5) size of plant, and (6) pod size, weight, and placement act in combination with the environment to produce a characteristic habit in beans. It was Norton's opinion that these characters must be analyzed in some detail in any inheritance study of habit. He concluded that axis length is conditioned by two or more factor pairs.

Morphological differences between pole and bush beans were described by Emerson (3, p. 19-31) in 1916 as part of a genetic study of plant height. Distinct examples of both bush and pole types were found to exist for internode length and number. In bush beans internode length was observed to increase under relatively favorable environmental conditions while internode number showed little change. Emerson also noted that maximum length was usually seen in the terminal internode in bush types. Branches were generally found to be more vigorous than the main axis.

In a concise review of the morphology of the bush bean, Nijdam (14, p. 453-457) considered number of internodes in the central stem, character of the terminal inflorescence, and the degree of branching of the central stem as predominant features determining habit. It was also concluded that varieties with a small number of vigorous branches usually set their pods high on the plant. Conversely, strongly branched varieties often have shorter branches and the pods appear to be more scattered around the plant. Nijdam viewed the normal bush bean as possessing a main axis of four to five internodes which progressively increase in length toward the terminal internode. The one or more lateral branches arise in the leaf axils and may in turn be branched to give a tiered effect. In terms of internode length and degree of branching the main axis appears compressed and thick-set near its base.

#### Early Inheritance Studies of Bush x Bush Crosses

Crosses of bush beans of differing mean internode length and number revealed to Emerson (3, p. 32-57) that these two characters were quantitatively inherited.  $F_1$  and  $F_2$  means tended to be intermediate for both internode length and number with a greater range of variation exhibited in the  $F_2$  than in the  $F_1$  or parents. Since mean internode length in certain crosses exceeded parental internode length, the indication was present in this early study of the varying relative



importance of additive and non-additive effects in conditioning internode length in bush beans.

Using height, dry weight of vines, leaf size, total number of internodes, and internode length as criteria of plant size, Malinowski (12, p. 1090-1093; 13, p. 96-110) observed striking heterosis in the  $F_1$  of reciprocal crosses between two pure-lined, non-twining bush beans. The parents also differed in the degree of branching exhibited. Although the  $F_1$  appeared to resemble one parent in this respect, the total amount of branching exceeded that found in either parent. Malinowski (13, p. 113-114) further observed that  $F_1$  plants, as opposed to plants of the parental varieties, exhibited greater response to the effects of day length on vegetative growth.

A detailed study of inflorescence branching was reported by Lamprecht (9, p. 71-93) in 1935. In the material used, the presence or absence of inflorescence branching was shown to be determined by a single factor pair with branching completely dominant to non-branching. Although no relation was observed between single and double branching, treble branching was found to be recessive to both.

#### Inheritance Studies of Interspecific and Other Wide Crosses

Many observations, including those of Gregor Mendel, have been made of interspecific crosses involving bush representatives of

Phaseolus vulgaris. Few workers, however, have studied in detail the inheritance of habit types produced from these crosses. Von Tschermak (17, p. 219-221) noted segregation for habit in progeny of crosses of P. vulgaris and P. multiflorus (coccineus) and concluded that several factors were involved in determining plant height.

In a later study Lamprecht (10, p. 136-150) described habit types produced in the  $F_3$  through the  $F_{11}$  from P. vulgaris x P. multiflorus crosses. Based largely on the direction of branching, three new habit types (pyramidal, prostrate, and horizontal) as opposed to the normal, determinate, upright bush type were observed. The effects of varying numbers of branches, tiers of branching, internode length, dwarfing, and inflorescence and leaf characteristics added to the array of habit types found. Lamprecht suggested that three genes for internode length, two for the direction of branching, and two each for number of tiers of branching and dwarfing could, as a very minimum, act as a basis for habit diversity. Also, the presence of genes with lesser effects was thought to be probable. In a study of dwarf, semi-dwarf, and normal determinate plants it was noted that no sharp boundary existed between groups.

Excessive vigor in total leaf area of  $F_1$  progeny from a cross of P. vulgaris var. Algarroba by Michelite, a navy bean, was concluded by Adams and Duarte (1, p. 380) to be the result of a multiplicative relationship between leaf number and mean leaf size.

Individually, these two components of leaf area behaved as though controlled by additive and completely dominant genes, respectively.

### Studies Involving Blue Lake Derived Bushes

Determinate plants in  $F_2$  populations of three bush x Blue Lake pole crosses were classified by Frazier (4, p. 417-420) as prostrate or erect in habit. Although classification had no well defined limits, the data indicated that a minimum of three recessive genes with major effects, or many minor genes, or both condition upright, bush habit of growth. In  $F_3$  studies a compressed dwarf habit with reduced internode length and number appeared to be conditioned primarily by three recessive genes.

Hess (6, p. 1-67) studied the parental lines,  $F_2$  populations, and randomly chosen  $F_3$  families involving a reciprocal cross between a true bush variety and an unrelated Blue Lake derived bush variety. The parents and  $F_2$ , grown under greenhouse and field conditions, showed the extreme influence of environment on central stem length, internode length, raceme number, number of branches, and plant stiffness. Winter greenhouse conditions tended to suppress differential expression of distinguishing characters which were quite evident in the field. Suppression of branching and raceme number was particularly striking and was considered to be sufficiently great under winter greenhouse conditions to reduce severely the efficiency

of selection.

Moreover, both the parental and the  $F_2$  populations behaved quite differently in the two environments. Wide variation in correlation was shown for number of internodes versus (1) number of racemes, (2) number of branches, and (3) central stem length.

Although exact recovery of parental types for gross habit of growth was not seen in the  $F_2$  or  $F_3$ , classification of approximate types followed by a chi-square test for goodness of fit indicated that possibly three major genes, or several minor genes, or both condition growth habit. Acknowledgment was made that the combined action of many minor genes might be interpreted statistically as due to the effects of a few major genes. As in earlier studies it was apparent that the measured morphological characters underlying habit were quantitatively inherited and strongly influenced by environment.

#### Influence of Environment on Bush Lima Beans Appears Similar

The extreme influence of environment on the bush snap bean may be similar to that observed in the bush lima bean. At various in-row plant spacings Havis (5, p. 451-454) concluded that the greater plant height seen at closer spacings was due primarily to greater internode elongation and not to an increase in internode number. Although plant spacing was constant in the investigation conducted by

Hess, environmental change was found to have a greater impact on internode length than on internode number in snap beans.

Havis also reported that bush limas grown under cheese cloth exhibited more internode elongation and a stronger tendency to twine. From experimental results and general field observation he concluded that reduction in light intensity and more rapid growth due to increases in soil moisture may operate to cause twining of the axis. During the period of most active growth two to three cloudy, humid days greatly promoted elongation of the upper internodes. Similar behavior of Blue Lake derived bush snap beans during warm, cloudy weather has been observed by Dr. W. A. Frazier at the Oregon Agricultural Experiment Station. True bush varieties have appeared to be less sensitive.

## MATERIALS AND METHODS

### Outline of Procedure

Basically, the investigation consisted of the screening of true bush varieties and derived bush lines which might possibly be used as parents, the hybridization of four of these, and the evaluation of their  $F_1$  and  $F_2$  progeny under several environmental regimes. In addition, evaluation of  $F_3$  and  $F_4$  derivatives of various other derived bush lines crossed with a true bush variety was made. These highlights of the procedure followed can logically be divided into several parts and presented in outline form as follows:

- A. The investigation began with two separate preliminary experiments designed to permit the observation of the behavior of possible parental material with regard to growth habit and other morphological characters.
  - 1. Nine varieties and lines were field planted at three in-row plant spacings.
  - 2. Two lines and one variety were subjected to a short period of shade at different times during growth.
- B. Progeny of four selected varieties and lines were examined in two inheritance studies of growth habit and

other morphological characters.

1. Parents and  $F_1$  families were grown in the greenhouse.
2. Parents and  $F_1$  and  $F_2$  families were grown at two in-row plant spacings at each of two times of planting in the field.

C. Further studies of the inheritance of these morphological characters were conducted by examining small families of  $F_3$  and  $F_4$  derivatives of crosses between a true bush variety and various derived bush lines. Both greenhouse and field plantings were made.

### General Methods of Plant Culture

Certain aspects of plant culture which were common to several of the experiments conducted during the investigation will be described in detail and during the description of the individual experiments, only mentioned briefly.

Greenhouse. Use was made of both groundbed and bench facilities in the greenhouse. In groundbed preparation through tillage of the sandy loam soil to a depth of six to seven inches was followed by a band application of 10-16-0 commercial fertilizer at a rate of approximately 400 pounds per acre. Water was applied by furrow

irrigation as needed.

In the bench greenhouse plants were grown in perforated number 10 cans of an unsterilized field soil- compost-sand mixture. The equivalent of five to six grams of 8-24-8 commercial fertilizer was thoroughly mixed with the soil in each can and seeds were planted on the smoothed, packed surface and were well covered with sand. After germination the plant population was reduced to four per can and each plant was supported by a wire stake.

In preparation for planting, either in the groundbed or in cans, only clean, bright seed of fairly uniform size was used. Immediately prior to planting, the seed was scarified to facilitate water uptake and, at the time of planting, dusted with Spergon.

Thermostatic control of steam heaters, wall coolers, and automatic ventilators provided approximate regulation of temperature at 60° - 65° F. and 75° - 85° F. night and day, respectively. The variable cloud cover characteristic of the spring and fall seasons rendered accurate temperature control during the day difficult.

Although the amount of natural light received was comparatively low during the winter season, no attempt was made to provide additional light.

Repeated dusting, spraying, and fumigation was necessary for the control of red spider mites and greenhouse whitefly.



Field. All field plantings were made in an alluvial silty clay loam of the Chehalis series at the Vegetable Crops Research Farm. In seedbed preparation thorough tillage was followed by a band application of 8-24-8 commercial fertilizer at a rate of approximately 400 pounds per acre. A hand-powered belt planter was used to space the Spergon-dusted seed along the row at a position slightly above and to one side of the fertilizer band. Only clean, bright seed of fairly uniform size was used.

Early in the growth of the crop weed control was accomplished by a pre-emergence application of DNPB (amine salts) at a rate of four pounds-active per acre. Hand hoeing and mechanical cultivation were employed as needed after the disappearance of pre-emergence effects. To reduce the likelihood of plant damage mechanical cultivation was avoided after plants began to fill the inter-row space.

Water was applied by overhead sprinkler irrigation every nine to ten days or as needed.

Insecticide applications were made as necessary.

### Characters and Criteria

Some of the characters measured or rated in any one experiment were also measured or rated in other experiments of the investigation. For this reason a description of all characters at this time

will avoid the necessity of repetitive description. During the explanation of procedures followed in individual experiments only a brief statement of the particular characters examined will be made.

All recorded measurements and ratings, except those made of pod set and of the height of immature plants, were made at the estimated time of pod maturity for commercial processing. Time of maturity was judged for each plot as a whole rather than for individual plants. Although character measurements or ratings were normally made on ten plants in each plot, there were rare occasions in which fewer than ten were available. To avoid bias plants in individual plots were measured or rated without knowledge of parentage.

Growth Habit. The general desirability of growth habit was rated on a zero to nine scale with nine being superior to zero. Plant erectness and stiffness, conformation, and point of pod attachment were considered in the evaluation of plant habit. Desirable conformation consisted primarily of medium height, freedom from excessive branching, and strong, firmly attached branches. High pod placement was also an important attribute of acceptable habit.

Pod Placement. Individual plants were rated on a zero to nine scale to designate the height of pod placement on the plant. A plant receiving a pod placement rating of nine would have a more desirable placement of pods than one given a rating of zero.

Plant Height. Height of plant was measured in centimeters or in inches from the ground surface to the outstretched tip of the terminal growing point at approximately 30 days after plant emergence or at times otherwise indicated. Early anthesis occurred at approximately 30-40 days following emergence.

Plant Length. The distance from the cotyledonary node to the outstretched tip of the most terminal growing point of the pulled plant was termed as plant length. In preliminary experiments this length was measured to the nearest one-half inch, while in later experiments measurements were taken to the nearest centimeter.

Length of the Longest Branch. The length of the longest branch was recorded to the nearest one-half inch from the point of its attachment on the central stem to the tip of its outstretched terminal growing point.

Length of Individual Internodes. Beginning with the cotyledonary node, the length of individual internodes in the central stem was measured to the nearest one-half inch or full centimeter, depending on the experiment.

Number of Internodes in the Central Stem. Internodes in the central stem were counted from the cotyledonary node to the beginning of the terminal raceme.

Number of Branches. Primary and secondary branches of

the central stem were counted. Very small undeveloped branches, although numerous in some instances, were counted only in the "spacing experiment". As in the study conducted by Hess (6, p. 7), the presence of one or more leaves together with one or more racemes satisfied the definition of branch.

Pod Set. The amount of pod set was rated on a zero to nine scale with zero and nine representing light and heavy pod set, respectively.

Yield. Yield was taken for each plot at the time of optimum pod maturity as judged by commercial standards.

Pod Color. Plants in the  $F_2$  populations derived from Pure-gold Wax were designated as either green or "wax" as determined by pod color.

#### Screening of Potential Parental Varieties and Lines in Preliminary Tests

While numerous well established true bush varieties were available for possible use in studies of growth habit, few Blue Lake derived bush lines representing diverse habit types were available with sufficient seed to permit preliminary testing. Elimination of many derived lines with poor habit characteristics and a recent massing of improved lines had reduced the diversity present in pure line form.

Varieties and Lines Screened. Ten varieties and lines representing true and derived bushes were selected in February, 1961, for preliminary observation and crossing studies. Several months later Puregold Wax, another true bush variety, was added.

As a group the OSU Blue Lake derived bush lines originated from a cross of Logan Bush x Rogers 6" pole made at the Oregon Agricultural Experiment Station in 1951. Using the FM-1 pole bean as a recurrent parent the original cross was followed by four to six backcrosses with determinate  $F_2$  plants. Successive single plant selection in the segregating generations after the last backcross gave rise to the several derived bush lines included in the present investigation. These lines, as well as the true bush varieties, will all be designated as "varieties" in subsequent sections of the text.

1. OSU 836-9. (Hereafter designated as 836-9). This derivative of the Oregon State University breeding program possessed a shorter, more upright habit than the average of breeding lines in a similar stage of development. The line was developed as a fourth backcross derivative from which single plants were selected in the  $F_2$  and  $F_3$  generations.

2. OSU 2466. (Hereafter designated as 2466). This line was derived from a single plant selected in the  $F_2$  and  $F_3$  generations following six backcrosses to FM-1 and possessed a distinctive dwarf

habit. Low-set, compressed dwarf types appear occasionally among segregating progeny of backcrosses of derived "bushes" to FM-1.

While their habit is inferior it was thought desirable to examine the behavior of this habit type with the more desirable growth habit exemplified by true bush varieties.

3. OSU 2189. (Hereafter designated as 2189). This line arose as an  $F_2$  selection following six backcrosses to FM-1. At the time of selection 2189 appeared to combine a slightly better than average habit with Blue Lake pod characteristics.

4. OSU 2061-2b. (Hereafter designated as 2061-2b). 2061-2b also arose as an  $F_2$  selection following six backcrosses to FM-1. The line seems to have a moderately sprawling habit along with pod quality approaching that of the recurrent Blue Lake parent.

5. OSU 797-1220. (Hereafter designated as 797-1220). Line 797-1220 was derived from a single plant selected in the  $F_2$  and  $F_3$  following four backcrosses to FM-1 and was similar to 836-9 in possessing a more upright habit of growth.

6. OSU 949-1864-2-1M. (Hereafter designated as 949-1864-2-1M). In the derivation of this line three backcrosses to FM-1 were followed by single-plant selection in six successive generations and a massing of several single plants of the seventh generation. Habit characteristics are similar to those of lines 2189 and 2061-2b.

7. White Seeded Tendercrop. (Hereafter designated as WST). The designation "White Seeded Tendercrop" has been placed on several lines and varieties selected in recent years. The variety used in this investigation was developed by Dr. J. D. Atkin of the New York Agricultural Experiment Station as a white-seeded sixth backcross derivative of Tendercrop x Streamliner (also called Granda) with Tendercrop serving as the recurrent parent. Under western Oregon conditions it appears to be virtually identical in habit to the original Tendercrop developed by Dr. W. J. Zaumeyer of the United States Department of Agriculture, Beltsville, Maryland.

WST, a true bush variety, possesses an excellent habit of growth. Under normal growing conditions the variety contrasts greatly with the OSU Blue Lake derived bushes by remaining stiffly upright, holding its pods well above the ground, and possessing strong, erect branches.

8. Puregold Wax. (Hereafter designated as PG). Puregold Wax is a true bush wax bean with a characteristic, somewhat heavily branched, fairly upright habit of growth. In addition, its recent use as a parent in the Oregon State University bean breeding program led to the hypothesis that possibly an association exists between pod color and some of the morphological characters contributing to habit differences. Its inclusion in the present investigation would provide a

means of testing this hypothesis.

PG was developed by the Rogers Brothers Company as a back-cross derivative of Brittle Wax x Wisconsin Hybrid Wax 536 with Brittle Wax serving as the recurrent parent.

9. Tendergreen. (Hereafter designated as TG). Tendergreen, a true bush variety of unknown parentage, was introduced to the seed trade by Peter Henderson and Company in 1922 and has been used as a commercial variety for many years. In overall appearance the variety is somewhat similar but slightly inferior in growth habit to WST. Plants are characterized by large vigorous growth, stout stems and rigid, heavy branches.

10. Sanilac. (Hereafter designated as Sanilac). This true bush pea bean variety was released in Michigan in 1956 as a derivative of an X-ray induced mutant of Michelite. By using the mutant as the recurrent parent Sanilac was developed as an  $F_4$  selection of the second backcross following a three-way cross involving derivatives of Robust, Crawford, Emerson 53, and Emerson 847.

Pea bean varieties represent a segment of the bean industry not carried on in western Oregon. However, their profuse branching gives rise to a distinct habit type which sets them apart from the derived and true snap bean bushes and it was considered desirable to include them in the present study.



11. Seaway. (Hereafter designated as Seaway). Seaway arose as an  $F_4$  selection following the fourth backcross to 8375 which was, in turn, obtained following three backcrosses of the Michelite Bush X-ray mutant to Michelite. Seaway and Sanilac are fairly similar in growth habit under western Oregon conditions.

Observation at Several Plant Spacings. To determine the influence of plant spacing on habit, ten varieties were planted in the field in May, 1961. A factorial design with five replications was used. Each replication contained one plot of each variety at each of three in-row plant spacings -- two, six, and twelve inches. Because the seed supply was limiting, the tenth variety, 2466, was planted only at the twelve-inch spacing and was saved for seed. PG was not included in the experiment.

Individual plots consisted of single rows 42 inches apart and 11 feet long with one foot remaining unplanted between plots along the row. Seed was planted thickly and after emergence plants were thinned to the desired spacing.

General observations were made throughout the growing season on habit characteristics in all plots. At the time of pod maturity a zero to nine rating of growth habit on a plot basis was made. Ten plants in each plot were then pulled and placed in plastic bags in cold storage. No plants of varieties 2466, 2189, 2061-2b, and Sanilac

were pulled and plants of varieties TG and Seaway were pulled from the two- and six-inch spacings only. As time permitted, numbers of branches on the stored plants were counted.

Analysis of variance was carried out according to the procedure described by Li (11, p. 316-318) for factorial experiments, and Duncan's multiple range test as described by Li (11, p. 238-241) was used to group the treatment means. Because recorded observations of numbers of branches were not made for all treatments, the data were analyzed both as a 2 x 6 factorial and as a 3 x 4 factorial and not as a 3 x 9 factorial as originally planned.

Observation after Shade Treatment. To determine the relative sensitivity of derived and true bushes to short periods of shade, plants of three varieties were covered with shade cloth for five days at various stages of development. The varieties used (WST, 2189, and 949-1864-2-1M) were those of which sufficient seed remained after the "spacing experiment".

The three varieties were planted in the field on June 21, 1961, in a split plot design with the eight times of shading shown in Table 1 serving as main plots and with varieties serving as single-row subplots randomized within main plots. Subplots were six feet long with two feet blank between plots along the row. Rows were spaced 38 inches apart. Seed was planted thickly and after emergence plants

were thinned to an average of two to three inches apart in the row.

As summarized in Table 1, the various times of shading were chosen to represent different morphological stages in the development of the bean plant. Shade was imposed by placing lightweight 2 x 9 x 11 foot wooden, shade cloth covered frames over the appropriate main plot of each of the three replications for a five day period. Thus, each main plot of three varieties was covered, as shown in Figure 1, only once during the growing season.

According to the manufacturer's specifications the plastic screen shade cloth allowed the transmission of 45 percent of the impinging light energy. A record of the normal solar radiation during the period of the experiment was obtained from the United States Department of Commerce (17, p. 318, 375, 427) in total Langleys per day from data taken from a pyrhelimeter at the Lewis-Brown Farm near Corvallis. A light meter was used occasionally to measure the light intensity beneath the shade cloth. No attempt was made to measure changes in temperature, humidity, and other environmental components which may have been influenced by the imposition of the shade treatment.

The following characters were measured or evaluated at the time of pod maturity or at times otherwise indicated:

1. Growth habit.

2. Plant length.
3. Height of plant in treatments one through four after the five days of shade in treatment four.
4. Number of internodes in the central stem.
5. Number of branches.
6. Length of the longest branch.
7. Length of individual internodes of the central stem.
8. Pod set at the conclusion of the last shade treatment.
9. Yield.

Growth habit, pod set, and yield were evaluated on a subplot basis whereas the several measured characters were recorded for 10 randomly chosen plants in each subplot. All measurements were recorded to the nearest one-half inch.

Because damp weather began to cause deterioration of plants prior to the conclusion of note taking, it was necessary to forego observation of some of the characters in certain of the treatments.

By following the procedure described by Snedecor (16, p. 309-313) an analysis of variance was made on plot means for each character. Data were transferred to punch cards and IBM equipment was used for the analysis. Duncan's multiple range test as described by Li (11, p. 238-241) was employed in grouping the treatment means for each character.

Table 1. Time at which shade was imposed on growing bush beans in the shade experiment.

Treatment number	Days after plant emergence	Morphological stage of development
1	--	Check - no shade imposed.
2	0	Plants emerging from ground surface.
3	6	Primary leaves fully expanded.
4	14	First trifoliate leaf fully expanded; second beginning to unfold in some instances. Very little stem elongation.
5	19	Third or fourth trifoliate leaf expanded; stem elongation now apparent. WST slightly slower.
6	27	Slide shoots and racemes beginning to elongate rapidly in 949-1864-2-1M and 2189.
7	34	Several days prior to full anthesis.
8	41	Small pods formed.



Figure 1. Shade cloth covered frames which were used to cover growing plants for five-day periods.

### Large-Scale Production of F<sub>1</sub> Seed

Parents Used. Based upon general observation and the results of preliminary tests, four varieties -- WST, PG, 836-9 and 2466-- were selected for hybridization and the six possible crosses and their reciprocals were made. Since it was thought desirable to observe the F<sub>1</sub> and F<sub>2</sub> progeny under several environmental regimes, a relatively large amount of seed was required. Furthermore, the need for overplanting and subsequent thinning of plants to obtain uniform plant stands increased seed requirements. Adequate amounts of F<sub>1</sub> seed were obtained by using approximately 150 plants of each parent.

Use of Greenhouse. The use of greenhouse facilities permitted the planting of successive crops for crossing purposes and reduced the effort involved in emasculation and pollination. Moreover, the possibility of contamination by foreign pollen is virtually eliminated under greenhouse conditions which exclude field insects.

Crossing Technique. The method outlined by Hikida (7, p. 15-16) was adopted to facilitate ease of crossing and increased set. Plump flower buds about one day from anthesis were opened and emasculated. The pollen-covered stigma of a freshly opened flower of the staminate parent was rubbed across the stigma of the emasculated bud. The opened, artificially pollinated bud was then carefully

closed and was sealed by sandwiching in a folded one-inch length of one-half-inch diameter cellophane tape. Several days after pollination the tape and enclosed bud dropped from the end of the elongated pod.

### Observation of Parents and F<sub>1</sub> Progeny in the Greenhouse

The four parents and their 12 F<sub>1</sub> families were planted in the greenhouse groundbed in January, 1962. A randomized block design with five replications was used. Single row, two-foot plots were used and rows were spaced two feet apart. Plants were thinned to an average distance of three to four inches apart in the row and were supported by string trellises to facilitate note taking.

Observations were made on five plants per plot. Height of plant was measured at thirty days after emergence. At pod maturity evaluation was made of growth habit, plant length, number of branches, number of internodes in the central stem, and the length of individual internodes in the central stem. Measurements were recorded to the nearest whole centimeter.

Using plot means across replications the percent deviation of each F<sub>1</sub> family from its respective midparent was calculated by the following formula:

$$\frac{F_1 - MP}{MP} \times 100 = \text{percent deviation,}$$



where  $MP = \frac{P_1 + P_2}{2}$ . Where applicable, the percent deviation of the  $F_1$  beyond the extreme parent (EP) in either the positive or negative direction, whichever was appropriate, was calculated by the following formula:

$$\frac{F_1 - EP}{EP} \times 100 = \text{percent deviation.}$$

### Observation of Parents and $F_1$ and $F_2$ Progeny in the Field

Field Layout and Procedure. The four parents together with their twelve possible  $F_1$  and  $F_2$  families were planted in the field in mid-May and in late June, 1962, at each of two in-row plant spacings in four replications of a split, split plot design. Two- and six-inch spacings were used. Times of planting were considered as main plots with spacings and the 28 genotypes (4 parents + 12  $F_1$  families + 12  $F_2$  families) designated as subplots and sub, subplots, respectively. The sub, subplots (hereafter designated as plots) consisted of single rows five and one-half feet long with two feet remaining unplanted between plots. Rows were spaced 36 inches apart.

One plot of each parent and of each  $F_1$  family was planted at each spacing at each time of planting while three plots of each  $F_2$  family were included in each of these four environments. Each replication of the experiment contained, therefore, 208 plots consisting of

52 plots at each plant spacing at each time of planting.

Seed for the  $F_2$  plots was obtained from  $F_1$  plants which had been grown in the greenhouse groundbed  $F_1$  diallel. Because the amount of seed produced was inadequate in some instances, a small amount of field-produced seed from  $F_1$  plants was added to the greenhouse grown seed in all  $F_2$  families. The proportion of field-grown seed and greenhouse-grown seed was constant for all  $F_2$  families.

The presence of a hard-seed-coat character necessitated the scarification of the seed of variety 2466, of  $F_1$  families in which this variety was used as a female and of its  $F_2$  families. Although no hard seed coat was evident in parental varieties PGand 836-9, the  $F_2$  seed of reciprocal crosses involving both of these varieties together possessed this character to a high degree. This unexpected difficulty necessitated scarification and replanting in several plots of the first planting. Scarification prior to planting alleviated the problem in the second planting.

In each plot the 10 plants to be later examined were staked after emergence and at approximately 20 days following emergence were marked by stapling a one-half x two-inch strip of heavy paper around the central stem. Although plants were chosen at random in plots at the two-inch spacing at the time of tagging, the small number of plants in plots at the six-inch spacing necessitated random selection at the time of thinning. To avoid border effects plants at the very

ends of plots were not used.

Height of plant was measured in centimeters at approximately the beginning of anthesis. At the time of pod maturity tagged plants were pulled, given a habit rating, and were placed on the ground along the row in the order in which they had appeared in the plot. As soon as possible the number of branches and central stem internodes were counted and measurements in centimeters was made of plant length and internode length. In the second planting a pod placement rating was also given at the time each plant was pulled.

### Analysis of Data

1. Analysis of Variance. Data were transferred to punch cards and split plot analyses of variance were carried out on IBM equipment.

2. Correlations. Simple correlations between characters were obtained for the parental,  $F_1$ , and  $F_2$  generations in each of the several environments by using the following formula:

$$r = \frac{SP}{\sqrt{SSx SSy}},$$

where SP equals the sum of the cross products of means, SSx equals the sum of the squared deviations from the mean of variable "x", and SSy equals the sum of the squared deviations from the mean of variable "y". This formula was also used to measure the degree of

association between the  $F_1$  and  $F_2$  generations for the several characters observed.

3. Chi-square tests of a possible association between pod color and morphological characters in individual  $F_2$  populations derived from PG were made. Data for these analyses were obtained from  $F_2$  families grown at wide spacing in the late planting. Somewhat greater uniformity of germination in the second planting and the opportunity for greater freedom of expression of the individual  $F_2$  genotypes at wide spacing were felt to provide for a more meaningful sampling of the data for this study. Since maternal effects were not evident, reciprocal crosses were combined.

4. Diallel Analysis. The graphic method of diallel cross analysis developed by Jinks and Hayman (8, p. 48-54) and as described by Allard (2, p. 70-78) was used to illustrate the possible mode of gene action involved in the inheritance of the several characters observed. A very brief description of diallel theory underlying the graphic method may illustrate its usefulness and limitations.

A diallel cross includes all  $n^2$  possible matings, including selfs and reciprocals, among  $n$  parents and may be illustrated in tabular form as shown in Table 2. Means across replications are used as entries in the diallel table. Prior to analysis reciprocals are combined and the resulting means are used to construct a new diallel

table which is, therefore, symmetrical across the diagonal of the selfed parents. A geometrical interpretation of the mode of gene action involved in the inheritance of the character in the population may be drawn from a minimum of two statistics calculated from the diallel table. These statistics are: ( $V_r$ ), the variance of all the offspring of each parent and, ( $W_r$ ), the covariance of all the offspring of each parent with the non-recurring parent. The slope ( $b$ ) and position of the regression line on a ( $W_r, V_r$ ) graph together with the position of plotted points can be interpreted in terms of gene action. In the present investigation 95 percent confidence limits were calculated for " $b$ ".

A hypothetical example based on a bigenic-biallelic model, as shown in Table 3, and assuming complete dominance, may serve to illustrate the details of the method. The regression line determined by ( $W_r, V_r$ ) values obtained from Table 3 may be seen in Figure 2 and may be expressed as  $\bar{y}_x = \bar{y} + b(x - \bar{x})$  where  $y$  and  $x$  refer to  $W_r$  and  $V_r$ , respectively. The slope of the regression line may be calculated by using the following formula:

$$b = \frac{SP}{SSx} ,$$

where  $SP$  equals the sum of cross products of the variances and covariances and where  $SSx$  equals the sum of the squared deviations of the variances from their mean.

In the absence of gene interaction the regression line has a

slope of unity and passes through the origin. Similarly, it can be shown that with partial dominance and overdominance the regression line intersects the  $V_r$  axis to the left and right of the origin, respectively. In the presence of gene interaction the slope of the regression line tends to deviate from unity.

Furthermore, the position of the  $(W_r, V_r)$  points on the regression line offers an indication of the relative concentration of recessive and dominant alleles among the parents which entered the diallel. It can be seen from Table 3 and from Figure 2 that  $(W_r, V_r)$  points of parents containing the dominant alleles tend to cluster toward the lower end of the regression line while the recessives are near the top. All points fall within a limiting parabolic curve described by the equation  $W_r^2 = V_r V_p$ , where the constant,  $(V_p)$ , is the variance of the parental array.

Allard (2, p. 87) points out that, in essence, the method allows the detection of the influence of three types of effects, namely, the additive effects, the non-additive effects, and "everything else". The "everything else", if present, upsets the classical pattern of behavior on the graphs.

It should be kept in mind that the graphic method is based upon the following assumptions:

1. The parents are homozygous.

2. The inheritance is diploid.
3. There is no linkage.
4. There is no gene interaction.
5. There are no maternal effects.
6. There are no multiple allelic series.

Table 2. Form of the diallel table with four parents.

		Male Parents			
		WST	836-9	2466	PG
Female Parents	WST	WST	WST x 836-9	WST x 2466	WST x PG
	836-9	836-9 x WST	836-9	836-9 x 2466	836-9 x PG
	2466	2466 x WST	2466 x 836-9	2466	2466 x PG
	PG	PG x WST	PG x 836-9	PG x 2466	PG

Table 3. A theoretical diallel table of genotypes and phenotypic values based on a bigenic-biallelic model with complete dominance in which aabb = 1.0, replacement of b by B adds 1.0, and replacement of a by A adds 2.0.\*

		Male Parents			
		AB	Ab	aB	ab
Female Parents	AB	AABB 4	AABb 4	AaBB 4	AaBb 4
	Ab	AABb 4	AAbb 3	AaBb 4	Aabb 3
	aB	AaBB 4	AaBb 4	aaBB 2	aaBb 2
	ab	AaBb 4	Aabb 3	aaBb 2	aabb 1
Vr		0.0	0.33	1.33	1.67
Wr		0.0	0.33	1.33	1.67
Vp					1.67

\* No relationship is implied between the entries in Table 2 and the specific genotypes and phenotypic values shown in Table 3.



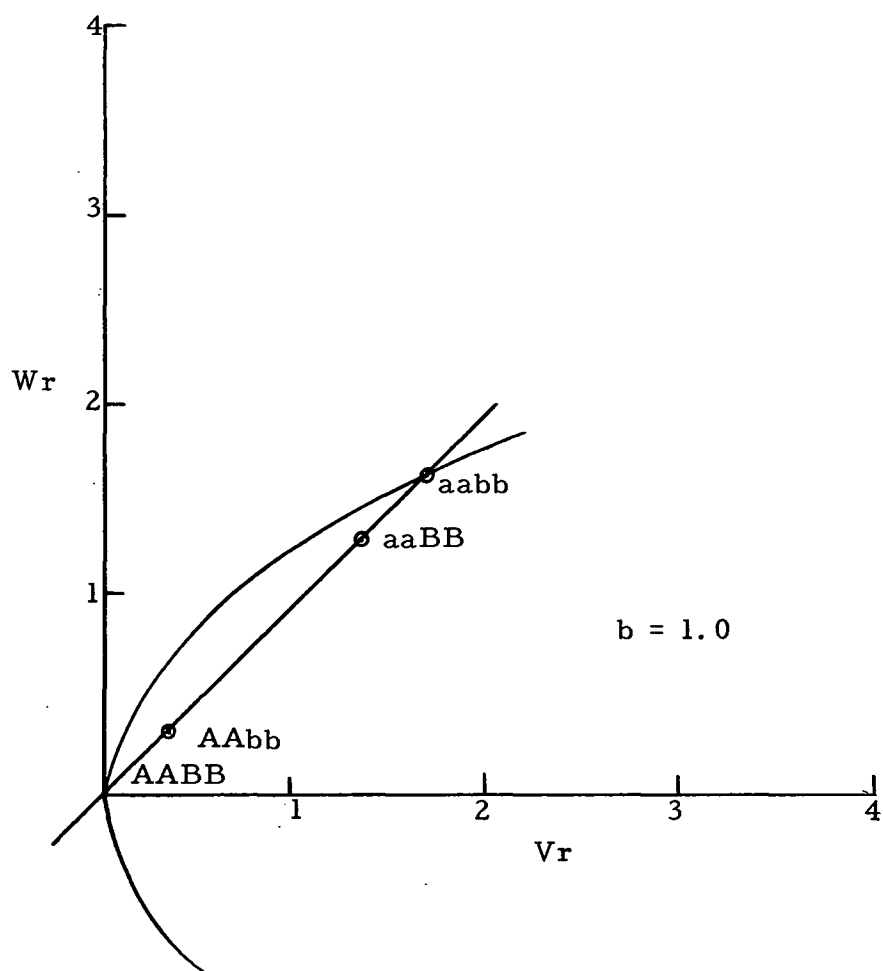


Figure 2. ( $W_r$ ,  $V_r$ ) graph calculated from the bigenic-biallelic model in Table 3.

Observation of  $F_3$  and  $F_4$  Derivatives  
of True x Derived Bush Crosses

During the past several years large  $F_2$  populations of WST x various Blue Lake derived bush lines have been grown as a part of the bean breeding program at Oregon State University. As standard practice  $F_2$  plants selected in the direction of improved habit have subsequently been observed as  $F_3$  families of several dozen to 100 or more plants which have provided a basis for further selection within and among families. Since the number of  $F_3$  families that can be handled in this manner limits either (1) the size of the  $F_2$  population that can be screened, or (2) the rigidity of selection from the  $F_2$  population, the question arose as to the value of harvesting only single pods from desirable  $F_2$  plants and the consequent screening of very small  $F_3$  families. If small  $F_3$  families would permit selection progress, the size of the  $F_2$  population could be greatly increased without changing the rigidity of selection.

During the winter of 1961-1962, two plants each of a large number of the more promising  $F_2$  segregates selected for better growth habit in the field the previous summer were grown in number 10 cans in the greenhouse. The following summer  $F_4$  seed and remaining  $F_3$  seed was used to establish a field planting of single-row, three-foot paired plots in rows 36 inches apart.

Height of plant measured to the nearest inch and a growth habit rating were recorded for each plant in the field and greenhouse at approximately the beginning of anthesis.  $F_3$  and  $F_4$  paired plot means were compared in the field planting by using the following formula:

$$t = \frac{\bar{y} - 0}{\sqrt{\frac{s^2}{n}}},$$

where  $s^2$  equals the variance of the differences,  $\bar{y}$  equals the mean difference and  $n$  equals the number of plot pairs. This "paired t" test was also used to compare means of field-grown derivatives of several  $F_3$  intra-family extremes which had been detected in the greenhouse. In addition, means were used to compute correlations between greenhouse-and field-grown  $F_3$  families.

## RESULTS

### Differential Response of Varieties in Preliminary Testing

In preliminary testing and observation it became apparent early in the growing season that plants of the true bush varieties were relatively sturdy and possessed slightly heavier, thicker stems which lacked the tendency to resemble a semi-runner. In WST, particularly, the central stem and branches from it remained upright and pods were free of contact with the ground. Upon development of its terminal raceme the central stem lost its supremacy and lateral shoots developed and flowered quickly. Anthesis occurred over a relatively short period of time.

The central stem of Blue Lake derived bush varieties displayed a more or less strong tendency, depending on the variety and on environmental influences, to elongate markedly at the upper two to three internodes. The semi-runner thus produced was a striking feature of habit and was progressively longer in the derived bush varieties planted at closer spacings. At anthesis, the runner normally ceased elongation, set several pods, and gradually dropped toward the ground where it assumed the appearance and role of a foot or "outrigger"<sup>1</sup> upon which the remainder of the plant rested.

<sup>1</sup> The term "outrigger" has been suggested by plant breeders, but original coinage of the term is unknown.

Elongating side branches which individually passed through a similar pattern of growth soon covered this outrigger. Anthesis was relatively prolonged.

Influence of Plant Spacing. As shown in Appendix Tables 21 and 22 analysis of variance for habit and number of branches revealed highly significant differences among varieties at the three plant spacings. In addition, highly significant variety x spacing interaction for both characters indicated that the several varieties responded differently at the three plant spacings.

The general observation that the derived bushes tend to exhibit more elongation of central stem and branch internodes was reflected in plant floppiness and, hence, in the habit ratings listed in Table 4. When compared with other derived bush varieties, however, 836-9 and 797-1220 possessed a more upright characteristic of growth. Derived bush varieties 949-1864-2-1M, 2061-2b, and 2189 were, as a group, so similar in habit characteristics and in general appearances that branches were counted only in the first of these three varieties.

Variety 2466, although not included in the statistical analysis, possessed a distinctive habit with fewer, shorter internodes, low placement of pods and a relatively compressed appearance. Typically, the central stem of 2466 consisted of three internodes in which

the third exhibited a moderate tendency to elongate.

Although the derived bushes tended to possess a more undesirable habit at closer spacing, WST presented a reversal of this response and at wider spacings tended to become too large and heavy to support its weight adequately. TG was characterized by a similar but less marked trend of response, although the greater "legginess" of this variety resulted in a relatively inferior habit appearance at all spacings. The two pea bean varieties also did not show significantly poorer growth habit at close spacing. These varieties were similar in appearance and did not appear to be well adapted to the overall environmental regime of the experimental area.

Varieties in which counts were made were progressively more branched at the wider spacings, with a greater difference in branching noted between the two- and six-inch spacings than between the six- and twelve-inch plant spacings (Table 5). Branches were most numerous in the pea bean varieties and derived bush varieties were intermediate in this respect. Compared to other bushes, WST possessed fewer branches at all three spacings.

Table 4. Growth habit means of several varieties of bush beans grown at two-, six- and twelve-inch in-row spacings.

Variety	Spacing (in inches)	Growth habit (0-9 rating)	Variety	Spacing (in inches)	Growth habit (0-9 rating)
WST	2	7.6 a*	Sanilac	6	5.4 f
WST	6	6.8 c	Sanilac	2	5.4 f
TG	6	6.4 cd	797-1220	2	4.4 g
WST	12	6.2 cde	949-1864-2-1M	12	4.4 g
836-9	6	6.0 def	2189	12	4.4 g
Seaway	2	6.0 def	2061-2b	12	4.2 gh
TG	2	5.8 def	836-9	2	4.0 ghi
Seaway	6	5.8 def	2061-2b	6	3.6 hi
836-9	12	5.6 ef	2189	6	3.4 ij
Seaway	12	5.6 ef	2189	2	2.8 j
Sanilac	12	5.6 ef	949-1864-2-1M	6	2.8 j
TG	12	5.4 f	949-1864-2-1M	2	2.6 j
797-1220	12	5.4 f	2061-2b	2	2.6 j
797-1220	6	5.4 f	2466**	12	1.0

\* Means followed by the same letter are not significantly different at the five percent level.

\*\* Variety 2466 did not enter into the analysis.

Table 5. Means of number of branches per plant on varieties of bush beans grown at several in-row plant spacings.

Analyzed as a 2 x 6 factorial*			Analyzed as a 3 x 4 factorial		
Variety	Spacing (in inches)	Number of branches	Variety	Spacing (in inches)	Number of branches
Seaway	6	28.1 a **	797-1220	12	22.6 a
949-1864- 2-1M	6	19.9 b	949-1864-2-1M	12	22.5 a
797-1220	6	19.5 b	836-9	12	21.6 a
836-9	6	17.9	WST	12	20.7 a
TG	6	17.6 c	949-1864-2-1M	6	19.9 ba
Seaway	2	17.3 c	797-1220	6	19.5 ba
WST	6	15.0 d	836-9	6	17.9 cb
836-9	2	13.9 e	WST	6	15.1 dc
949-1864- 2-1M	2	13.3 e	836-9	2	13.9 ed
797-1220	2	13.1 e	949-1864-2-1M	2	13.3 ed
TG	2	8.9 d	797-1220	2	11.1 e
WST	2	8.6 d	WST	2	8.6 f

\* Because recorded observations were not made on all plots, the data were analyzed both as a 3 x 4 and as a 2 x 6 factorial.

\*\* Means followed by the same letter are not significantly different at the five percent level.



Influence of a Short Period of Shade. The five-day periods of shade given to plants of WST, 949-1864-2-1M, and 2189 did not exert an equal influence on plant development at the various stages of growth. Analyses of variance, as summarized in Appendix Tables 23 through 31, and the ranking of means presented in Table 6, illustrate for the particular characters evaluated the relatively greater sensitivity of plants at approximately 15 to 20 days after emergence. Further survey of these analyses reveals that variety x time-of-shading interaction was present with several of the characters observed, particularly those involving stem elongation. The differential varietal response implied by these interactions is illustrated in Appendix Figures 22 through 30 by the stability of WST and relative instability of 2189 and 949-1864-2-1M, the two derived bush varieties.

The period of time from 14 to 18 days after emergence included the beginning of the period of rapid elongation of the central stem. Shading increased this elongation but did not increase numbers of internodes or branches. Shading prior to ten days did not seem to exert either an immediate or a delayed effect on the morphological characters observed.

The amount of solar radiation received in the general area of Corvallis was not greatly reduced for prolonged periods during the course of the experiment (Appendix Figure 31). Except for the

seventh, ninth, and thirtieth day after emergence, clear or nearly clear weather prevailed. Light-meter readings revealed that the intensity of radiation received under the shade cloth on a sunny day exceeded that normally received at the ground surface on a heavily overcast day.

1. Growth Habit. The last five-day shade treatment ceased 46 days after plant emergence and check plots were considered to have reached maturity 14 days later. At this time only plants of the last treatment were significantly inferior in habit (Table 6). Although intervarietal habit differences were evident throughout the duration of the experiment, differences within varieties (between check and shaded plots) were much less apparent at maturity than they were immediately following shade cloth removal in treatments which began at 14, 19, 27, 34, and 41 days after emergence. As indicated in Table 6 and Appendix Figure 22 varieties 2189 and 949-1864-2-1M were inferior in habit to WST.

2. Plant Height. The ranking of means in Table 6 illustrates the marked increase occurring in the height of bushes given shade beginning at the 14th day following emergence. Furthermore, a highly significant variety x time interaction indicated that 2189 and 949-1864-2-1M were more sensitive to shade treatment. The relatively greater stability of WST is indicated in Appendix Figures 20, 21, and 23.

3. Plant Length. Sensitivity of plants at approximately 15 to 20 days after emergence was further demonstrated by an increase in the overall length of plant in derived bushes (Appendix Figure 24). The data in Table 6 show that plant length in 2189 exceeds that of 949-1864-2-1M and both were longer than WST.

4. Mean Length of Central Stem Internodes. The behavior of internode length closely paralleled that of plant height and length. It may be seen from Table 6 and Appendix Figure 25 that the internodes of the central stem of WST were shorter and did not elongate under the influence of shade treatments.

5. Number of Central Stem Internodes. Analysis of variance followed by the ranking of means seen in Table 6 indicated (1) that the central stem of the derived bushes (2189 and 949-1864-2-1M) consisted of fewer internodes, and (2) that this character was not influenced by the shade treatments. While WST possessed more central stem internodes than the two derived bush varieties, it can be seen from Table 6 and Appendix Figure 26 that this difference is in an absolute sense not great.

6. Length of the Longest Branch. Analysis of variance revealed highly significant variety differences in branch length (Appendix Table 28). The data in Table 6 show that branch length increased from WST to 2189 to 949-1864-2-1M, in that order, while means for

time of shading were not significantly different.

7. Number of Branches. The ranking of means in Table 6 suggests (1) that the number of branches is increased if shade is applied during a sensitive period, and (2) that this sensitive period compares favorably with that exhibited by plants for the several characters which involve stem elongation. Although variety differences in branch number were apparent, it could not be concluded from variance analysis that shade effects differed at the five percent level. The number of branches was lowest in WST and greater in the derived bushes (Table 6 and Appendix Figure 28).

8. Pod Set. Two weeks prior to harvest, variation in pod set became noticeable among the treatments. Accordingly, a rating of plots on a zero to nine basis followed by analysis of variance, summarized in Appendix Table 30, demonstrated treatment and varietal differences. The results of a multiple range test of the means listed in Table 6 indicated that fewer pods were set in plots subjected to five days of shade beginning at 14 days after emergence even though shade cloth had been removed from these plots approximately three weeks prior to full anthesis. Shading of plants prior to 14 days was less influential on pod set than treatment of plants older than 19 days. Nevertheless, shading during and immediately prior to anthesis did not reduce pod set greatly. Plants with fewer pods and therefore

less pod weight at maturity were thought to possess a more upright habit.

Although it is suggested in Appendix Figure 29 that variety 2189 was somewhat more sensitive, analysis of variance as summarized in Appendix Table 30 did not reveal variety x time-of-shading interaction.

9. Yield. The harvest data confirmed, generally, the results of the pod set evaluation made two weeks earlier (Table 6 and Appendix Figure 30). It was noted that a larger proportion of small pods was included in the yield from the shade treatment which began 14 days after plant emergence.

Table 6. Means of several characters as influenced by variety and time of shading in the shade experiment. As determined by a multiple range test, means followed by the same letter are not significantly different at the five percent level.

Growth habit rating (0-9)		Height of plant in inches <sup>x</sup>		Plant length in inches <sup>y</sup>		Mean internode length in inches		Length of longest branch in inches	
Time <sup>u</sup>	Mean	Time	Mean	Time	Mean	Time	Mean	Time	Mean
41	3.7 a <sup>v</sup>	Check	6.3 a	Check	22.9 a	Check	3.0 a	Check	19.1 a
34	4.3 ab	6	7.0 a	6	24.3 ac	6	3.1 a	14	19.5 a
14	4.6 b	0	7.8 a	0	24.4 ac	41	3.2 a	27	19.6 a
6	4.6 b	14	10.6 b	41	25.2 ac	27	3.3 ac	6	19.9 a
0	4.8 b			27	25.6 ac	14	3.6 bc	0	20.3 a
Check	4.9 b			14	26.4 bc	19	3.7 b	19	21.4 a
19	5.1 b			19	28.6 b			41	21.8 a
27	5.2 b								
949 <sup>w</sup>	3.7 a	WST	4.6 a	WST	21.5 a	WST	2.7 a	WST	17.6 a
2189	4.3 b	2189	9.3 b	949	25.3 b	949	3.5 b	2189	21.6 b
WST	5.9 c	949	9.8 b	2189	27.2 c	2189	3.7 b	949	22.6 c
Number of Internodes		Number of branches		Pod set (0-9)		Yield in tons per acre			
Time	Mean	Time	Mean	Time	Mean	Time	Mean	Time	Mean
0	5.6 a	6	7.9 a	14	3.2 a	14	5.5 a		
Check	5.6 a	Check	8.4 a	34	4.4 b	41	6.0 ac		
27	5.6 a	41	8.5 a	19	4.8 cb	19	6.3 bc		
14	5.6 a	27	9.0 a	41	4.8 cb	Check	6.6 bc		
19	5.7 a	19	9.0 a	0	5.2 cb	6	6.7 bc		
6	5.7 a	14	10.3 a	6	5.3 cb	34	6.8 bc		
41	5.7 a			Check	5.7 cb	27	6.8 b		
				27	5.8 c	0	7.1 b		
949	5.6 a	WST	7.1 a	2189	3.8 a	2189	5.9 a		
2189	5.7 a	949	9.3 b	WST	5.3 b	WST	6.6 b		
WST	5.9 b	2189	10.1 c	949	5.6 b	949	6.9 b		

u Time refers to the number of days after emergence at which the five-day shade treatment began.

w 949-1864-2-1M has here been shortened to 949.

x Height of plant was measured from the ground level to the outstretched tip of the terminal growing point at 19 days after plant emergence.

y Length of the pulled plant at pod maturity was measured from the cotyledonary node to the tip of the most terminal growing point.

### Performance of Parents and $F_1$ and $F_2$ Progeny

Individual parent and  $F_1$  progeny means for the various characters observed in the greenhouse diallel are listed in Appendix Table 44, while parental,  $F_1$ , and  $F_2$  progeny means together with analyses of variance appertaining to the field plantings are presented in Appendix Tables 32 through 43. A summarization of these means from the greenhouse and field may be seen in Table 7. Gross phenotypic differences between parental varieties and their progeny are illustrated in Appendix Figures 34 through 39. The four parental varieties as a group are shown in Appendix Figure 32.

General Notes on Plant Growth. Weather conditions varied widely between the two times of planting in the field. Immediately prior to and for several weeks after the planting made on May 15, cloudy, cool weather acted to delay germination and development. Conversely, the later planting, made on June 30, was subjected to relatively bright, warm conditions. Germination and development were rapid and, as is evident from the means listed in Table 7, plants reached much greater size than in the early planting.

Plants grown in the greenhouse differed markedly from field-grown plants in possessing a more spindly habit, larger leaves, and a more fragile appearance. The degree of difference was slightly

smaller between greenhouse-grown plants and plants from the later of the two field plantings.



Table 7. Generation means within environments for the various characters observed in the field diallel.

			Character						
Generation	Planting	Spacing	Growth habit (0-9 rating)	Pod placement (0-9 rating)	Plant height in centimeters <sup>u</sup>	Plant length in centimeters <sup>v</sup>	Number of branches	Number of internodes	Mean internode length in centimeters
Parents	Early	Close	5.84		16.19	30.47	4.10	3.96	4.09
		Wide	6.10		13.49	31.33	6.71	4.00	2.82
	Late	Close	4.64	6.56	33.94	48.57	6.62	4.86	6.11
		Wide	4.65	5.48	26.97	47.82	10.65	4.91	4.69
	Greenhouse---		4.31		55.80	59.95	4.60	3.91	13.11
	-----								
F <sub>1</sub>	Early	Close	5.15		19.32	42.70	4.61	3.61	4.89
		Wide	6.00		17.28	45.11	7.89	3.69	3.64
	Late	Close	3.32	6.38	45.05	62.48	7.59	4.51	6.58
		Wide	3.33	5.45	46.97	62.84	11.78	4.53	4.88
	Greenhouse---		3.30		64.06	72.89	3.78	3.65	16.31
	-----								
F <sub>2</sub>	Early	Close	5.86		19.58	40.24	4.92	4.10	4.94
		Wide	5.96		16.94	40.06	7.88	4.07	3.73
	Late	Close	4.23	6.44	37.17	53.27	6.94	4.83	6.38
		Wide	4.25	5.67	30.55	53.61	11.21	4.82	4.86

<sup>u</sup> Height of plant was measured from the ground level to the outstretched tip of the terminal growing point at approximately 30 days after emergence.

<sup>v</sup> Length of the pulled plant at pod maturity was measured from the cotyledonary node to the tip of the most terminal growing point.

Table 8. Correlation coefficients between the  $F_1$  and the  $F_2$  for various characters observed in the field diallel.

Character	Early planting		Late planting	
	Close spacing	Wide spacing	Close spacing	Wide spacing
Growth Habit	.88**	.73**	.87**	.80**
Plant Height	.66**	.62**	.59**	.73**
Plant Length	.53**	.41**	.29	.60**
Number of Branches	.42**	.37**	.24	.49**
Number of Internodes	.83**	.67**	.88**	.83**
Mean Internode Length	.45**	.47**	.36*	.18
Pod Placement			.67**	.75**
n =	48	48	48	48

\* and \*\*      The value for "r" is significant at the five and one per-cent levels, respectively.

Growth Habit. An examination of the means shown in Table 7 and the analysis of variance summarized in Appendix Table 33 indicate that growth habit varied greatly with the environmental regime at which the field diallel was planted. In general, habit appeared to be inferior at close spacing regardless of the time of planting. At both spacings, however, habit was relatively inferior in the late planting.

The relation of the  $F_1$  progeny means to their respective midparent and extreme-parent values may be seen in Table 9. In both the field and greenhouse  $F_1$  progeny of unlike parents consistently tended to fall below their midparent values for habit.  $F_1$  versus midparent relationships in crosses between true and between derived bush varieties, however, were not consistent between the field and greenhouse.

For each parent in combination with the other three Figure 3 graphically illustrates the relationship of mean midparent, mean  $F_1$ , and mean  $F_2$  to the mean parental value for habit. The consistent tendency of regression of the  $F_2$  in the direction of the midparent can be seen in Table 9 and in Figure 3.

Diallel analysis of the  $F_1$  and  $F_2$  habit means composited across the field environments is summarized in the (Wr, Vr) graphs in Figure 4. In these graphs the absence of significant departure of

the slope of the regression line from 1.0 indicates that interaction is not playing a major role in the overall action of the genes conditioning growth habit. Furthermore, the position of the regression line to the left of the origin is a gross indication that the net effect of genes conditioning growth habit is one of partial dominance. In addition, the scatter of points along the regression line suggests that WST and PG possess a relatively higher concentration of recessive alleles while 2466 and 836-9 possess more of the dominant alleles. Wide separation of the ( $W_r$ ,  $V_r$ ) points for true-bush versus derived-bush parental arrays suggests that a small number of genes or major genes condition habit difference between these two types of bushes.

The dominance of poor habit may be seen in Appendix Figures 25 through 39. The overall degree of heterosis for size, branching, and length for  $F_1$  plants of crosses between WST and 836-9 is quite apparent in Appendix Figure 35.

Table 9. Deviation of the  $F_1$  from the mean midparent and beyond the extreme parent for growth habit in the greenhouse and field diallels, and  $F_2$  depression in the field diallel.

Cross	Percent deviation of the $F_1$ from mean midparent		Percent deviation of the $F_1$ beyond extreme parent		Percent $F_2$ depression
	Greenhouse	Field	Greenhouse	Field	Field
WST x 836-9	-33.4	-14.3	-13.3	-----	-14.6
WST x 2466	-25.8	-16.7	-----	-----	-14.1
WST x PG	2.2	-10.2	-----	-8.3	- 6.1
836-9 x 2466	-12.6	18.4	-----	-----	- 8.4
836-9 x PG	-38.1	-33.0	-29.8	-----	-16.0
2466 x PG	-37.9	-23.0	-15.3	-----	-11.7
Mean	-23.6	-15.4			-11.6

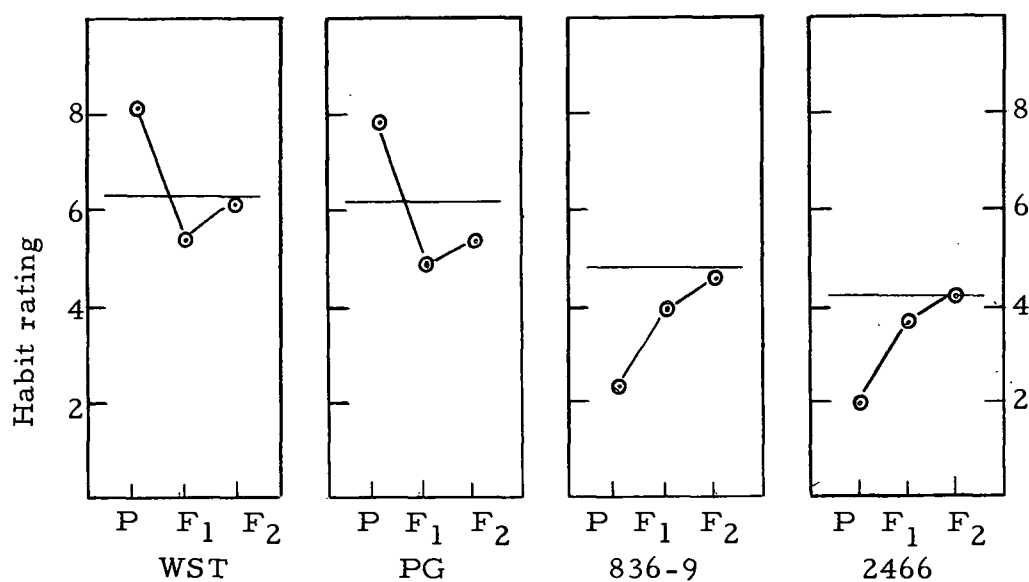


Figure 3. Graphic comparison of the generations for growth habit composited across environments of the field diallel. The mean midparent values are shown by horizontal lines.

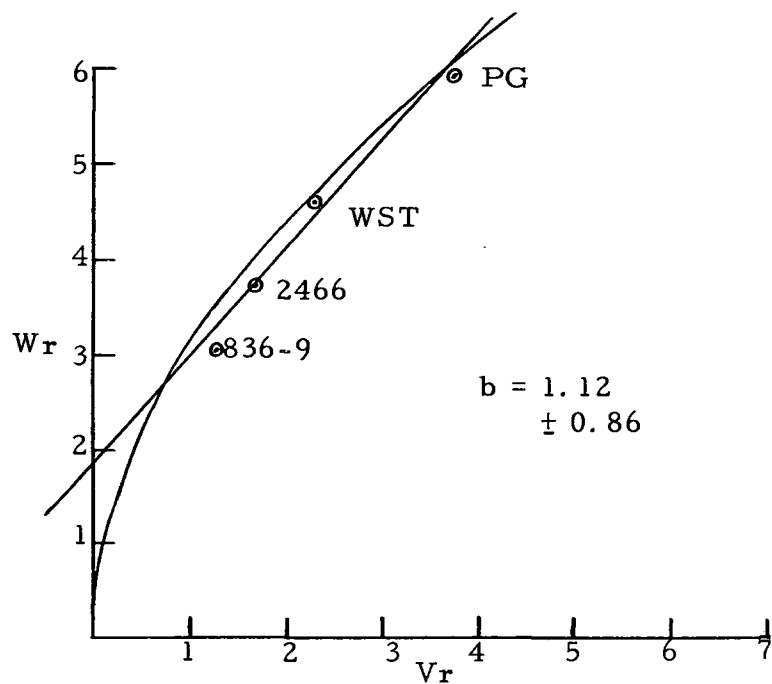
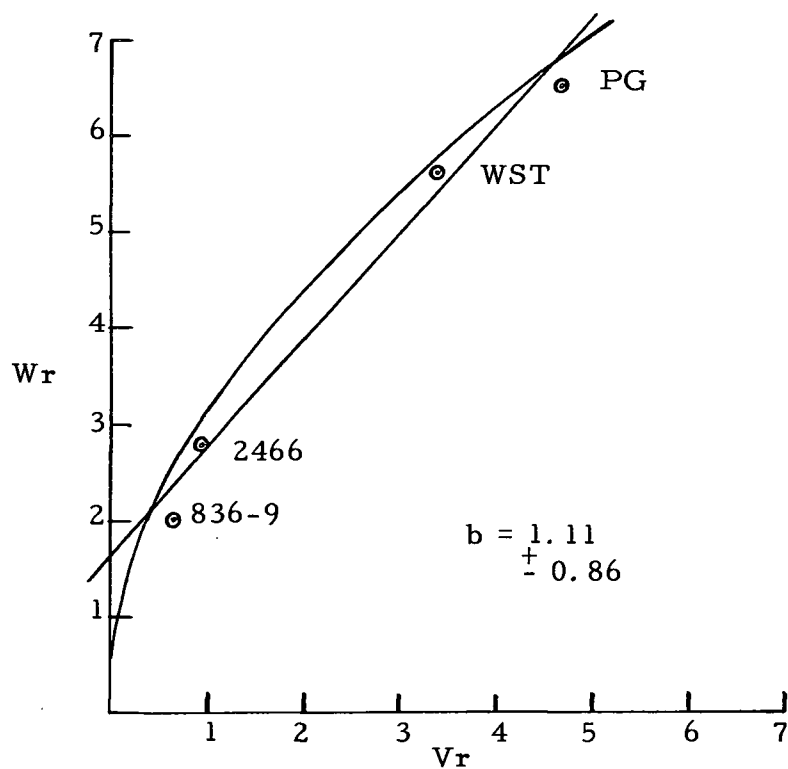


Figure 4. ( $W_r$ ,  $V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from growth-habit data from the field diallel. Ninety-five percent confidence limits of  $b$  are given.

Pod Placement. Genotype means for pod placement in both spacings of the late planting of the field diallel are listed in Appendix Table 43. In both environments 2466 possessed a low mean rating for pod placement while 836-9, PG, and WST, in that order, received higher ratings. Throughout the generations mean ratings appeared to be slightly lower at the six-inch than at the two-inch spacing (Table 7).

The two true bush parents, WST and PG, did not appear to behave similarly in crosses with derived bush varieties.  $F_1$  means of crosses of PG with 2466 and 836-9 were above the midparent (Table 10 and Appendix Figures 37 and 38). Conversely, the  $F_1$  of WST crossed with these two derived bushes fell below the midparent (Table 10 and Appendix Figures 35 and 36). The  $F_1$  of crosses between true and between derived bushes also fell below the midparent.

Dissimilarity of behavior is also seen in the depression of the  $F_2$  (Figure 5 and Table 10). Regression toward the midparent is probably non-existent in the  $F_2$  of crosses of PG with 2466 and 836-9, while no consistent tendency is seen in the  $F_2$  of crosses of WST with the derived bush varieties. As seen from Table 8, the overall association between the  $F_1$  and the  $F_2$  is high for pod placement.

Analysis of the diallel table for the  $F_1$  and  $F_2$  populations

confirms the indications shown in Table 10 and Figure 5 that pod placement is conditioned by genes exhibiting a net effect of partial dominance. In both graphs the agreement of the slope of the line of regression with unity verifies the absence of detectable interaction.

Diallel analysis of both the  $F_1$  and the  $F_2$  suggests that a higher concentration of dominant alleles is possessed by PG. Although points representing the arrays of parents WST, 836-9, and 2466 fall on the recessive end of the regression line when compared with PG, the order within these three is not constant from the  $F_1$  to the  $F_2$  and, therefore, they cannot be assigned genotypic values relative to one another. Genetic differences separating PG from WST, 836-9, and 2466 as a group appear to be greater than differences within this group.



Table 10. Deviation of the  $F_1$  from the mean midparent, deviation of the  $F_1$  beyond the extreme parent, and  $F_2$  depression for pod placement in the field diallel.

Cross	Percent deviation of the $F_1$ from the mean midparent	Percent deviation of the $F_1$ beyond the extreme parent	Percent $F_2$ depression
WST x 836-9	- 4.4	-----	5.1
WST x 2466	- 9.6	-----	-10.5
WST x PG	- 7.5	- 3.9	- 3.7
836-9 x 2466	- 5.9	-----	-10.0
836-9 x PG	4.4	-----	1.9
2466 x PG	13.3	-----	0.3
Mean	- 1.8		- 2.4

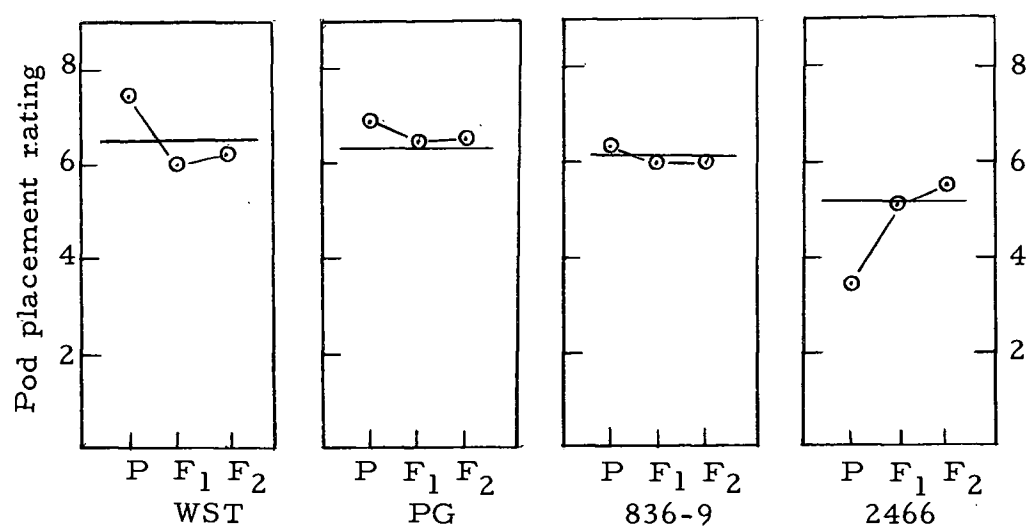


Figure 5. Graphic comparison of the generations for pod placement composited across environments of the field diallel. The mean midparent values are shown by horizontal lines.

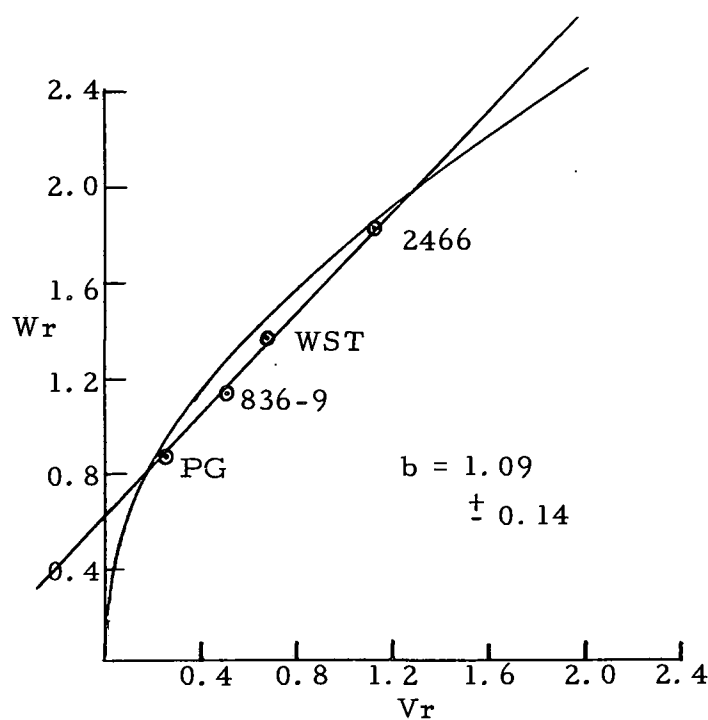
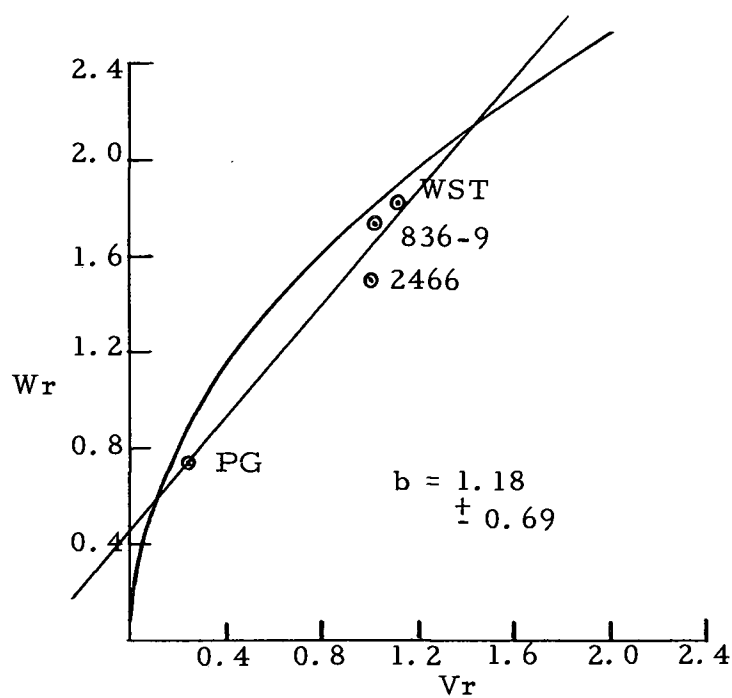


Figure 6. ( $W_r$ ,  $V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from pod-placement data from the field diallel. Ninety-five percent confidence limits of  $b$  are given.

Plant Height. Across  $F_1$  families mean height of plant at 30 days after emergence increased relatively little from wide to close plant spacing but more than doubled from the first to the second planting (Table 7). Variance analysis revealed highly significant differences between spacings, plantings, and both within and among parents,  $F_1$ , and  $F_2$  populations (Appendix Table 35). Interaction effects were also revealed both for parents and the  $F_1$  versus both time of planting and plant spacing.

The degree of departure of the  $F_1$  from the midparent and from the  $F_2$  may be seen in Table 11 and in Figure 7. With the exception of crosses between the two derived bush varieties, the  $F_1$  families in the field diallel exceeded the midparent and the extreme parent. The magnitude of this relative vigor of the hybrids between true and derived bush varieties is vividly illustrated in Appendix Figures 35 through 38.

In the greenhouse diallel the pattern of results did not appear to be as constant. Mean values for  $F_1$  families of crosses between derived bush varieties and between true bush varieties fell below the midparent.  $F_1$  families between derived and true bush varieties exceeded the midparent and extreme parent, although in the cross involving WST and 2466 maternal effects were evident (Table 11).

The comparison of means for the various generations, both

in Figure 11 and in Table 7, reveal, therefore, that non-additive effects are extremely important in conditioning plant height and it is not surprising to find that the  $(W_r, V_r)$  graphs in Figure 8 present a very erratic behavior. Points representing the parental arrays are widely scattered and significant regression is not evident in the  $F_1$  or the  $F_2$ . Removal of each of the four parents in turn and analysis of each of the four resulting  $3 \times 3$  diallel tables failed to remove interaction and to restore the slope of regression to 1.0. Analysis following the deletion of parental array 2466, as shown in Figure 9, brought about a greater apparent correction in graph appearance than removal of any of the three remaining parents. However, the variation inherent in the construction of a regression line from only three points does not allow the detection of a significant regression in the case of the  $(W_r, V_r)$  graphs in Figure 9.

Table 11. Deviation of the  $F_1$  from the mean midparent and beyond the extreme parent for height of plant in the field and greenhouse diallels, and  $F_2$  depression in the field diallel.

Cross	Percent deviation of the $F_1$ from the mean midparent		Percent deviation of the $F_1$ beyond the extreme parent		Percent $F_2$ depression
	Greenhouse	Field	Greenhouse	Field	Field
WST x 836-9	27.8	23.8	7.1	3.8	14.8
WST x 2466	- 2.3	13.6	-----	3.2	- 8.4
2466 x WST	39.0	24.1	13.1	12.7	2.2
WST x PG	-12.8	26.6	-----	14.8	7.6
836-9 x 2466	-14.9	- 3.0	-13.5	-----	- 7.4
836-9 x PG	38.5	42.4	31.9	30.4	13.6
2466 x PG	31.0	52.0	22.9	51.7	10.8
Mean	14.8	26.7			6.4

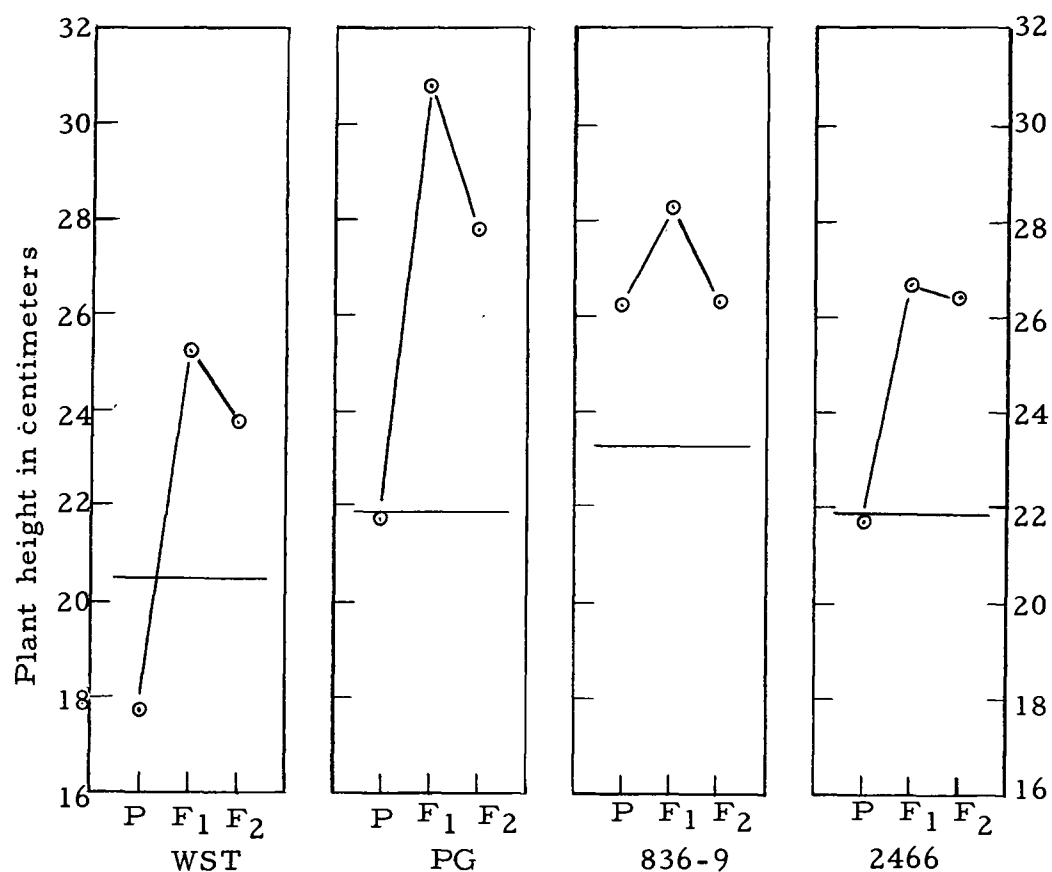


Figure 7. Graphic comparison of the generations for height of plant at 30 days after emergence and composited across environments of the field diallel. The mean midparent values are shown by horizontal lines.

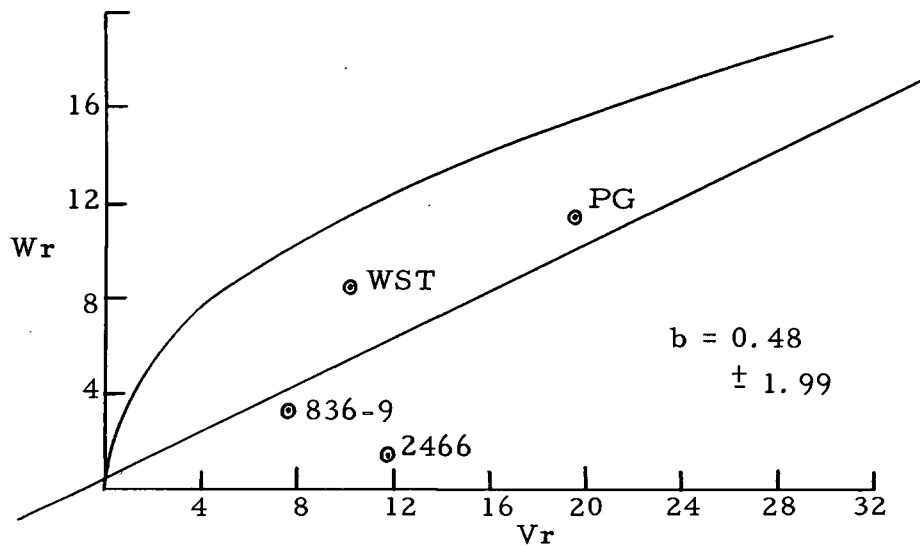
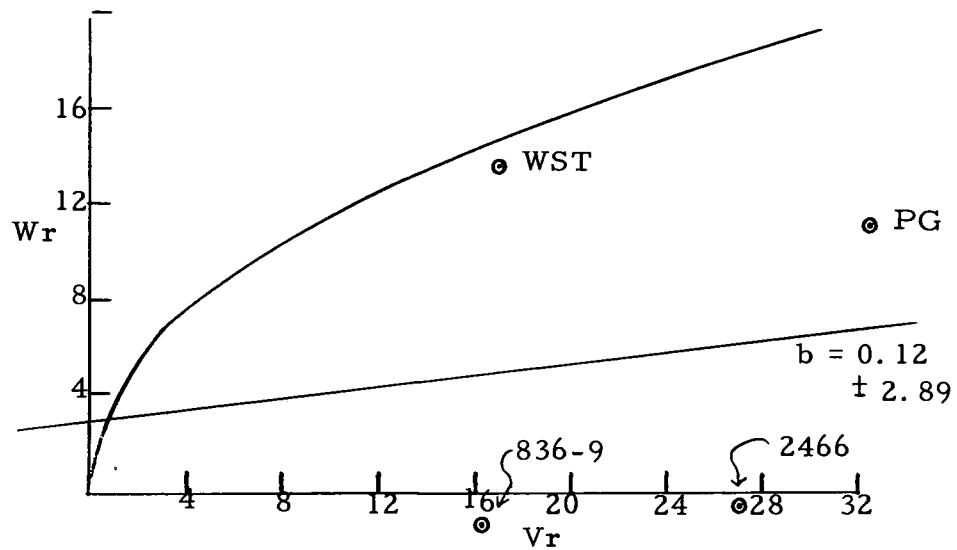


Figure 8. ( $W_r$ ,  $V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from height-of-plant data from the field diallel. Ninety-five percent confidence limits of  $b$  are given.

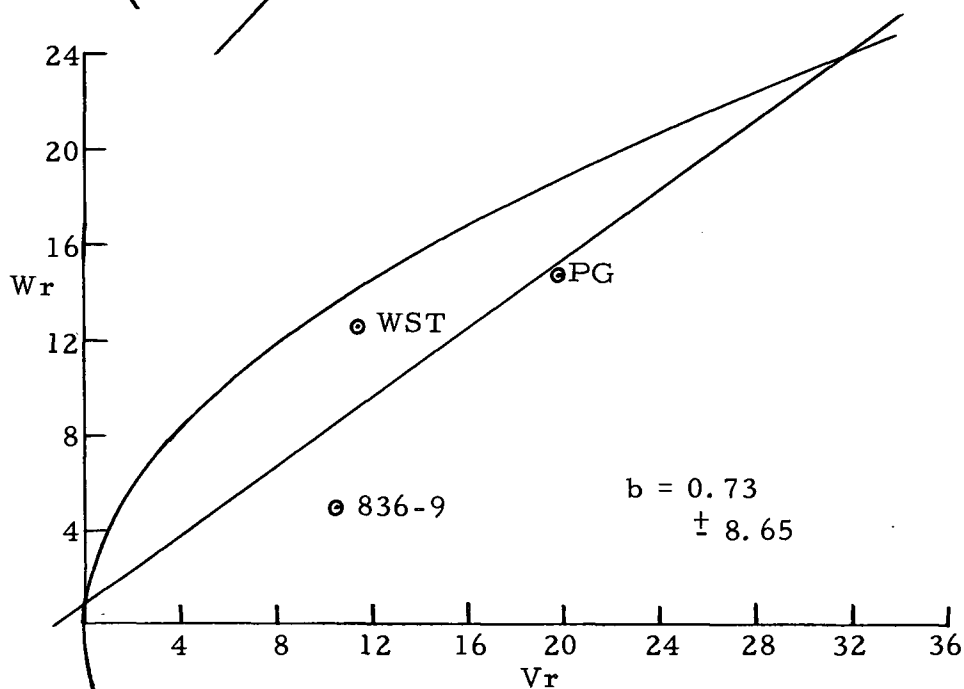
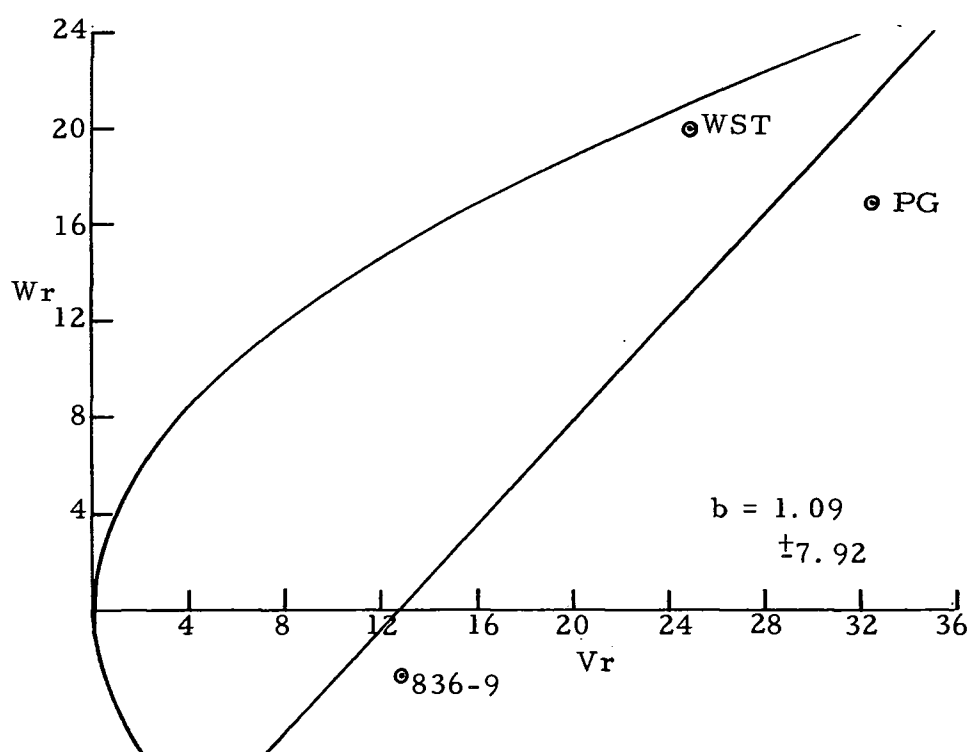


Figure 9. ( $W_r$ ,  $V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from height-of-plant data from the field diallel with parental array 2466 omitted. Ninety-five percent confidence limits of  $b$  are given.

Plant Length. The behavior of plant length at maturity was similar to that of plant height taken at 30 days after emergence. Plant length, however, represented a better indication of the overall plant growth achieved by the time of pod maturity.

Examination of the results of variance analysis in Appendix Table 37 together with the tabulation of means in Table 7 shows that the greater mean length of plant at the later planting was highly significant. Conversely, no difference with regard to plant spacing was noted. A highly significant genotype x time-of-planting interaction could not be attributed to interaction within the parental,  $F_1$ , or  $F_2$  population, but rather to differences of behavior among these three populations with change in time of planting.

As seen in Table 12 and Figure 10, marked heterosis, indicated by deviation of the  $F_1$  from the extreme parent, was noted for plant length. The  $F_1$  mean of crosses between true and derived bush varieties fell well above the midparent in the field, while the  $F_1$  mean of crosses between true bush varieties and between derived bush varieties fell above the midparent in the field and below in the greenhouse.

Under greenhouse conditions maternal effects were evident in the  $F_1$  of reciprocal crosses of WST with 2466 (Table 12). However, the marked heterosis exhibited in the greenhouse by the  $F_1$  of



2466 x WST compared closely with the performance of the  $F_1$  of both 2466 x WST and WST x 2466 in the field.

The results of diallel analysis (Figure 11) reflected the presence of extreme heterosis and the regression line fell far to the right of the origin on the ( $W_r$ ,  $V_r$ ) graphs. The scatter of points from the line was sufficient in both graphs, however, to preclude the certainty of significant regression. Analysis of 3 x 3 diallel tables constructed by removing each parental array in turn did not correct the slope of the regression line toward unity.

The scatter of points along the line indicated that the derived bushes tend to possess a larger proportion of the recessive alleles for plant length. While differences between true bushes and between derived bushes appear to be smaller than the difference separating these two types, ( $W_r$ ,  $V_r$ ) points representing each type fall quite far from the parabola-regression line intersections. Hence, the two derived bush varieties and the two true bush varieties probably do not represent extremes in possible dominance and recessiveness, respectively, for plant length.

Table 12. Deviation of the  $F_1$  from the mean midparent and beyond the extreme parent for plant length in the greenhouse and field diallels; and  $F_2$  depression in the field diallel.

Cross	Percent deviation of the $F_1$ from the mean midparent		Percent deviation of the $F_1$ beyond the extreme parent		Percent $F_2$ depression
	Greenhouse	Field	Greenhouse	Field	Field
WST x 836-9	33.2	44.2	14.1	41.4	26.8
WST x 2466	8.2	58.3	-----	49.3	36.0
2466 x WST	46.0	50.1	24.5	41.5	27.7
WST x PG	-15.1	27.8	- 3.4	26.4	12.7
836-9 x 2466	-10.6	5.1	-10.1	-----	0.2
836-9 x PG	45.5	45.8	36.2	43.4	10.0
2466 x PG	45.7	41.1	35.7	34.4	8.9
Mean	21.6	36.1			15.0

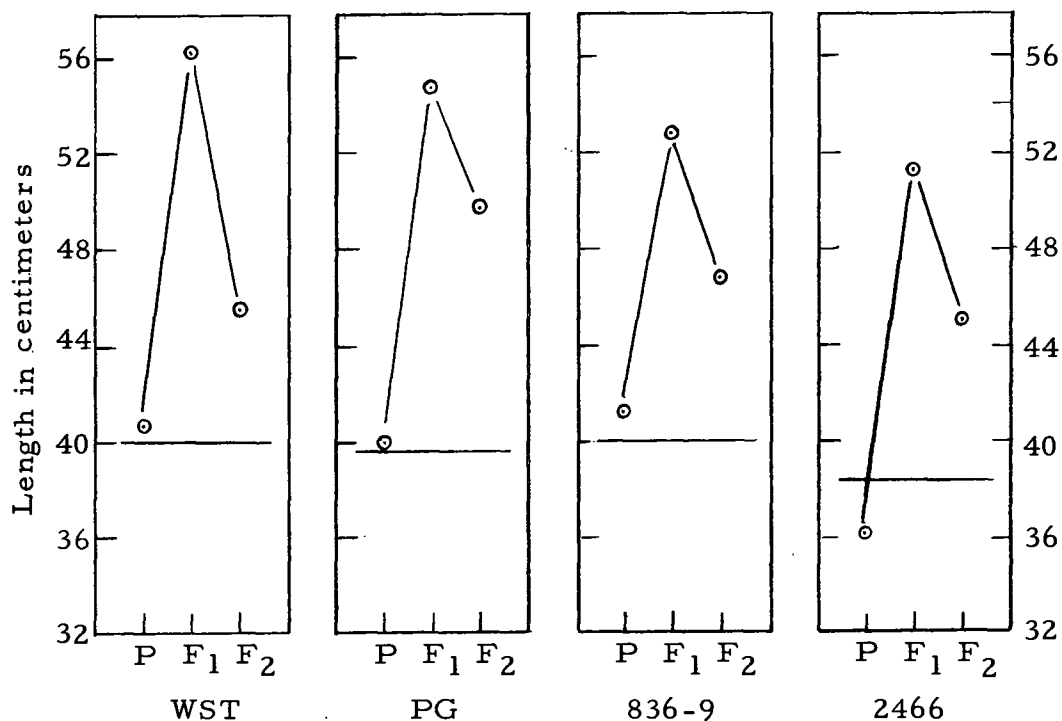


Figure 10. Graphic comparison of the generations for plant length composited across environments of the field diallel. The mean midparent values are shown by horizontal lines.

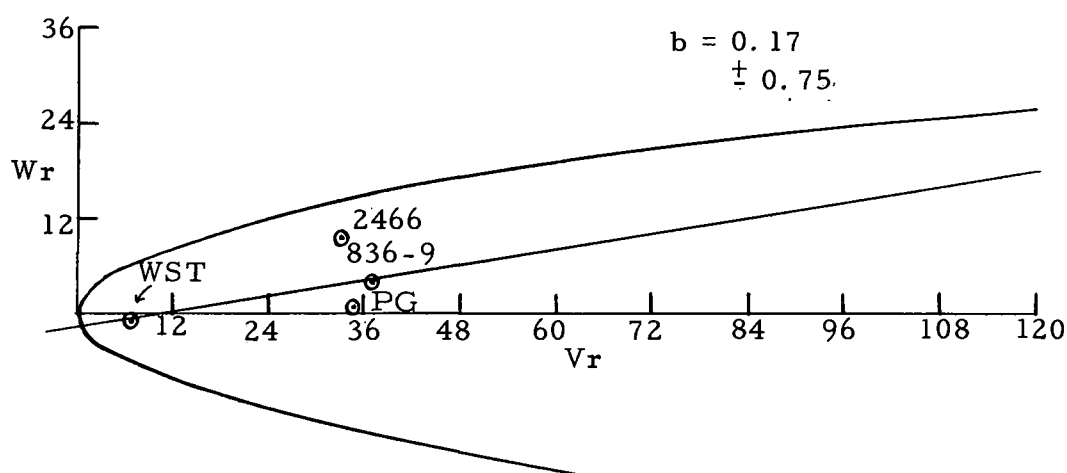
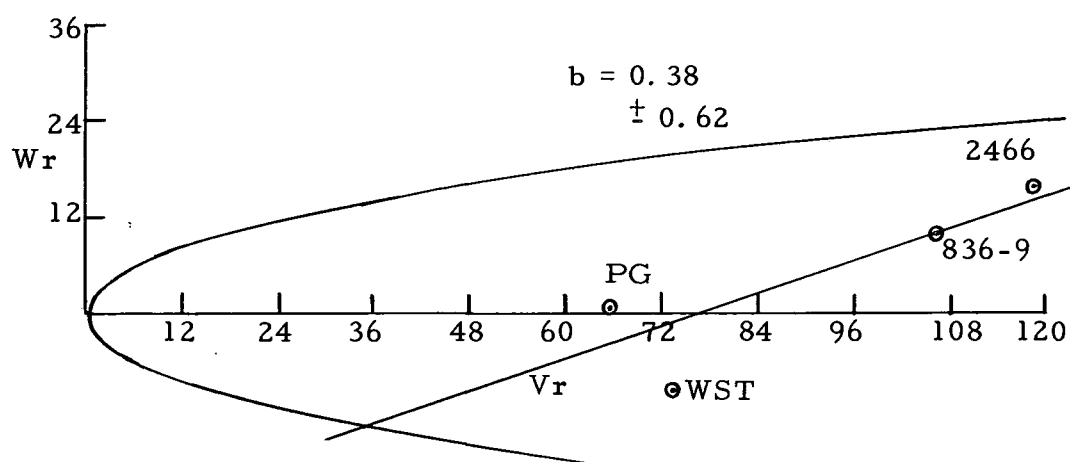


Figure 11. ( $W_r$ ,  $V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from plant-length data from the field diallel. Ninety-five percent confidence limits of  $b$  are given.

Number of Branches. The degree of branching, determined by the number of branches from the central stem, was very greatly influenced in the field by time of planting and by plant spacing. Analysis of variance (Appendix Table 42) and the listing of means (Table 7) reveal that wide spacing and later planting both caused a highly significant increase in number of branches. Significant or highly significant second and third order interactions between genotypes and either spacing, or time of planting, or both were revealed throughout the analysis. Very strong genotype x environmental interactions were indicated within the parental,  $F_1$ , and  $F_2$  populations.

Even fewer branches were produced by plants grown under greenhouse conditions. It may be seen in Table 7 that branch numbers were low in the greenhouse when compared with any or all field environments. Furthermore, the comparison of generations in both the field and greenhouse plantings revealed a reversal of relationship between the  $F_1$  and midparent (Table 13). In the field,  $F_1$  families of crosses between true and derived bushes tended to exhibit greater branching than the midparent and in several instances exceeded the extreme parent, whereas negative heterosis was found in the greenhouse. Under field conditions  $F_1$  plants of reciprocal crosses of WST with 2466 possessed approximately 25 percent more branches than the more heavily branched parent and, in the

greenhouse, approximately 20 percent less than the lower parent.

While  $F_2$  depression was noted for progeny of crosses between WST and the two derived bush varieties, the  $F_2$  progeny of crosses between PG and these derived bush varieties showed little deviation from the  $F_1$  (Table 13). Considering all families, the association between the  $F_1$  and the  $F_2$  is, as seen in Table 8, highly significant in all environments except in the close-spaced late planting.

The  $(W_r, V_r)$  graphs of Figure 13 suggest that the gene system conditioning the expression of number of branches exerts a net effect of partial dominance. Masked in this "net effect", however, is the heterosis expressed in crosses between WST and the derived bush varieties.

WST and 836-9 appear to possess a greater concentration of recessive alleles than does 2466, although there is some lack of consistency between the  $F_1$  and the  $F_2$  in this respect. The scatter of points along the regression line is not great in comparison to the boundaries imposed by the limiting parabola and one is led, therefore, to believe that genetic differences among the parents are due mainly to genes with small effects.

The  $(W_r, V_r)$  graph for the  $F_1$ , although normally easier to interpret, does not confirm or contradict the results of analysis of

the  $F_2$  (Figure 13). Removal of the four parents in turn does not greatly change the appearance of the graphs. Although removal of the array representing 2466 appears to correct the slope of regression toward unity in Figure 14, the reduced precision inherent in three as compared to four points on the graph does not permit real improvement of the original analysis.

Table 13. Deviation of the  $F_1$  from the mean midparent and beyond the extreme parent for number of branches per plant in the greenhouse and field diallels, and  $F_2$  depression in the field diallel.

Cross	Percent deviation of the $F_1$ from the mean midparent		Percent deviation of the $F_1$ beyond the extreme parent		Percent $F_2$ depression
	Greenhouse	Field	Greenhouse	Field	Field
WST x 836-9	3.6	31.9	-----	12.2	19.0
WST x 2466	-20.5	36.0	-20.3	24.8	14.0
WST x PG	-39.1	2.8	-12.1	-----	- 3.8
836-9 x 2466	-22.4	3.2	- 6.1	-----	- 2.8
836-9 x PG	- 2.8	15.5	-----	6.7	- 1.9
2466 x PG	-22.2	4.5	-----	-----	- 1.6
Mean	-17.7	14.6			3.2

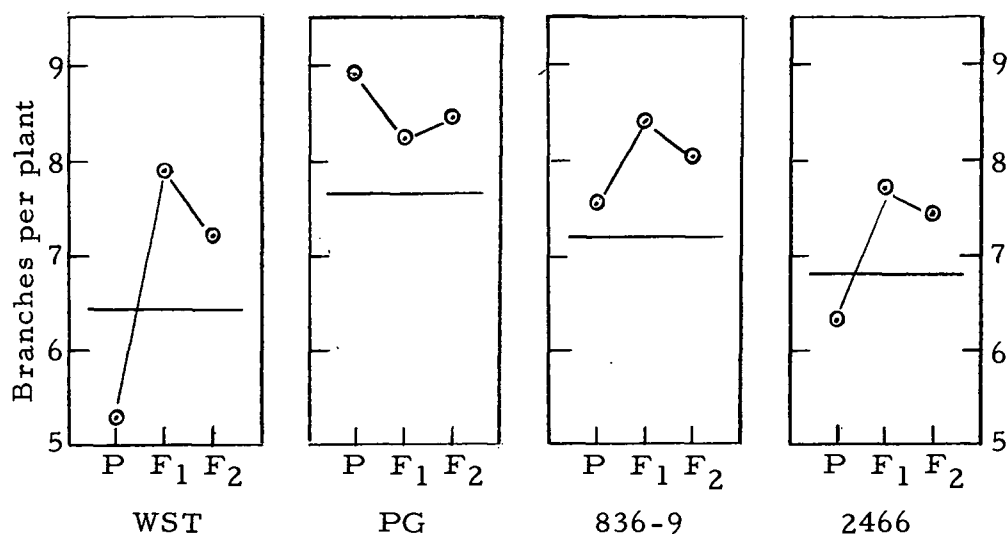


Figure 12. Graphic comparison of the generations for number of branches per plant composited across environments of the field diallel. The mean midparent values are shown by horizontal lines.

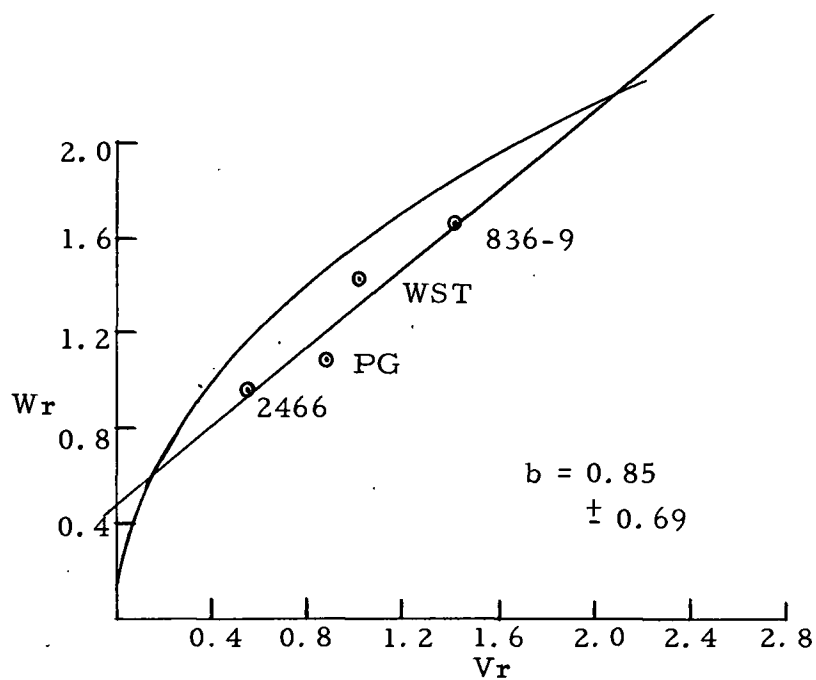
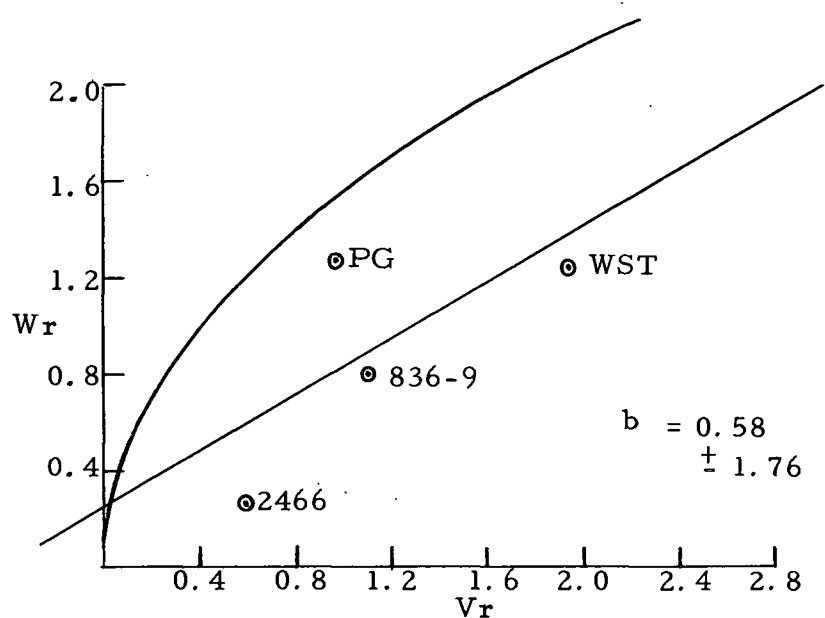


Figure 13. ( $W_r$ ,  $V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from number of branches per plant in the field diallel. Ninety-five percent confidence limits of  $b$  are given.



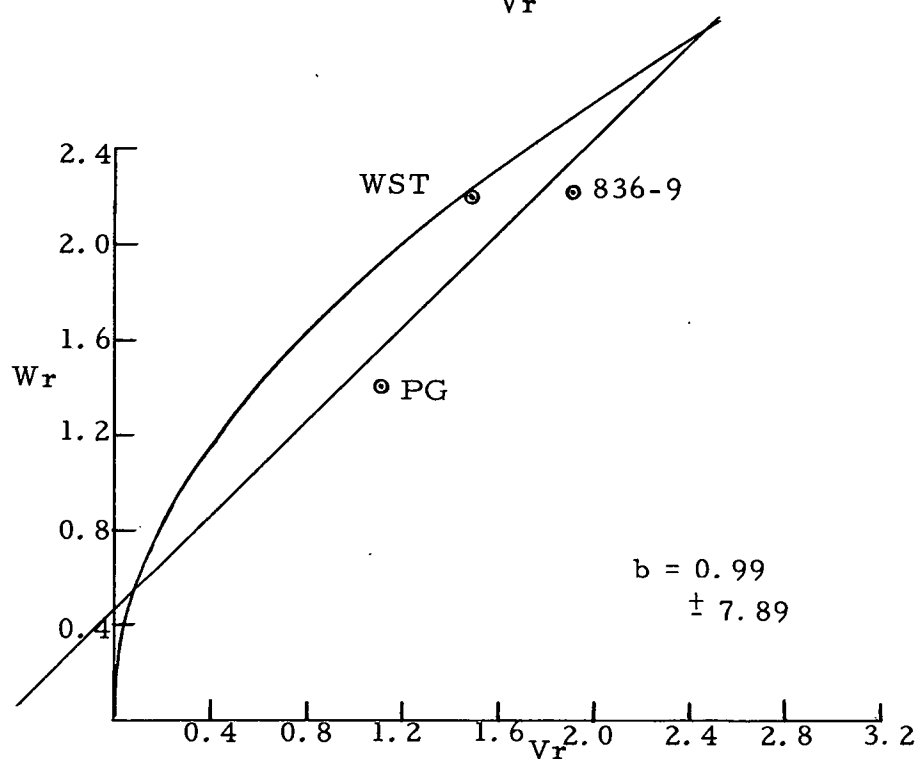
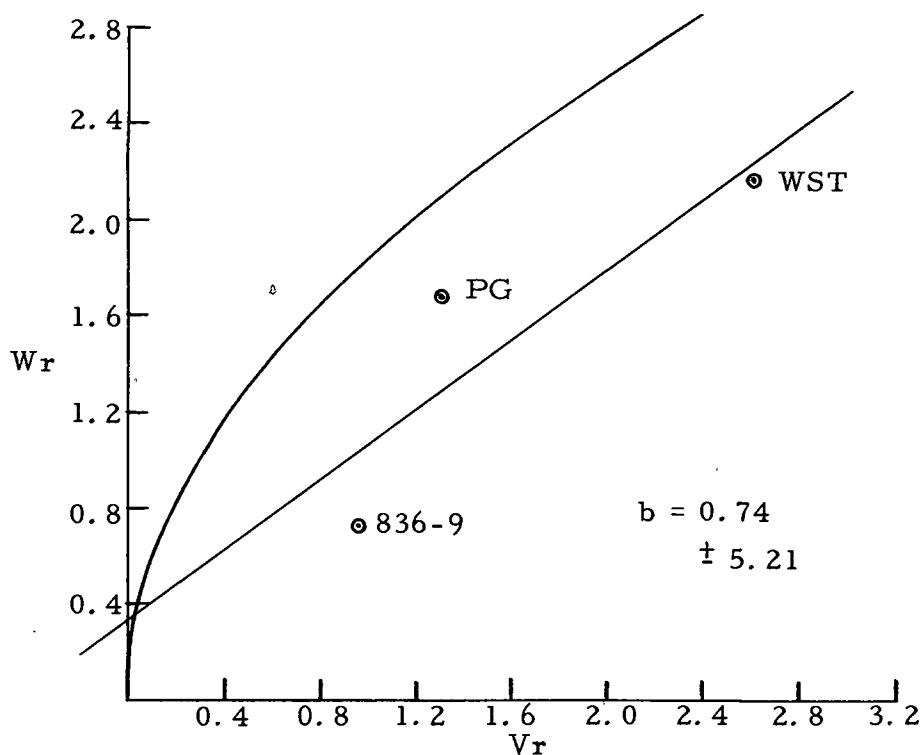


Figure 14. ( $W_r$ ,  $V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from number of branches per plant in the field diallel with parental array 2466 omitted. Ninety-five percent confidence limits of  $b$  are given.

Number of Central Stem Internodes. Changing environment seemed to have less effect on internode number than on the several other characters observed. Internode number remained constant over all three generations with change in plant spacing, but increased somewhat from the earlier to the later planting (Table 7). In the  $F_1$  the average increase seen in the late June planting approximated one internode.

Although analysis of variance revealed the presence of interaction between  $F_1$  genotypes and both spacing and time of planting (Appendix Table 40), the relationship between the  $F_1$  families composited across field environments and the  $F_1$  families in the greenhouse was very close (Table 14 ). There was a general tendency for the  $F_1$  to fall below the midparent (Table 14 and Figure 15). However, it can be seen from Table 14 that the magnitude of this departure was consistently greater for all crosses involving variety 2466.

The depression of the  $F_2$  seems to be somewhat greater than would be expected, particularly in two of the three crosses showing little if any deviation from the midparent. It may be seen in Table 14 that these two crosses both have PG as a common parent, with WST and 836-9 as parents not in common. As a whole, however, the depression of the  $F_2$  is not excessive and the association between

the  $F_1$  and the  $F_2$  is highly significant (Table 8).

Examination of the ( $W_r$ ,  $V_r$ ) graphs for the  $F_1$  and the  $F_2$  suggests that the net effect of the genes conditioning internode number is one of partial dominance (Figure 16). The slope of the regression line on both graphs does not deviate significantly from 1.0. Variety 2466, the low-internode-number parent, appears to carry a high concentration of dominant alleles. The remaining three parents, while carrying more of the recessive alleles, do not maintain their relative position on the regression line in the  $F_1$  and  $F_2$  and further assignment of genotypes would be hazardous.

Table 14. Deviation of the  $F_1$  from the mean midparent and beyond the extreme parent for number of central stem internodes in the greenhouse and field diallels, and  $F_2$  depression in the field diallel.

Cross	Percent deviation of the $F_1$ from the mean midparent		Percent deviation of the $F_1$ beyond the extreme parent		Percent $F_2$ depression
	Greenhouse	Field	Greenhouse	Field	Field
WST x 836-9	0.6	0.0	-----	-----	- 0.4
WST x 2466	- 8.5	-10.5	-----	-----	- 7.8
WST x PG	- 3.1	- 2.8	-----	-----	- 6.1
836-9 x 2466	-14.7	-10.4	-----	-----	- 7.3
836-9 x PG	- 2.8	- 1.0	-----	-----	- 9.0
2466 x PG	-14.0	-12.8	-----	-----	- 8.6
Mean	- 6.6	- 5.8			- 6.4

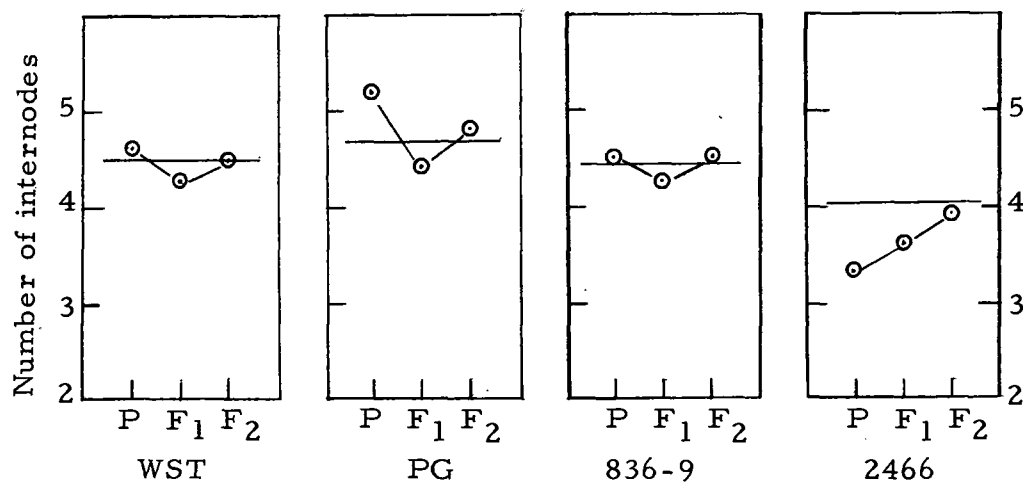


Figure 15. Graphic comparison of the generations for number of internodes in the central stem composited across environments of the field diallel. The mean midparent values are shown by horizontal lines.

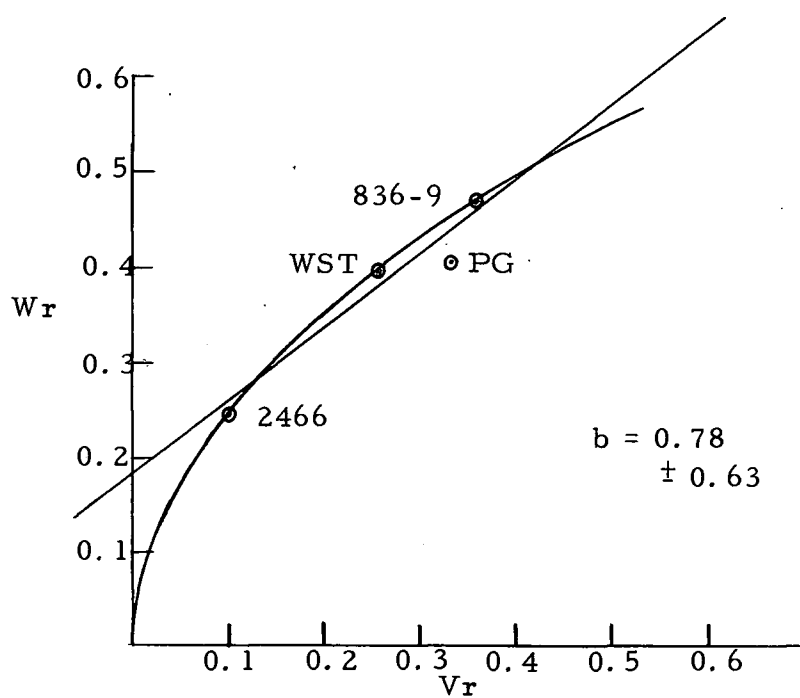
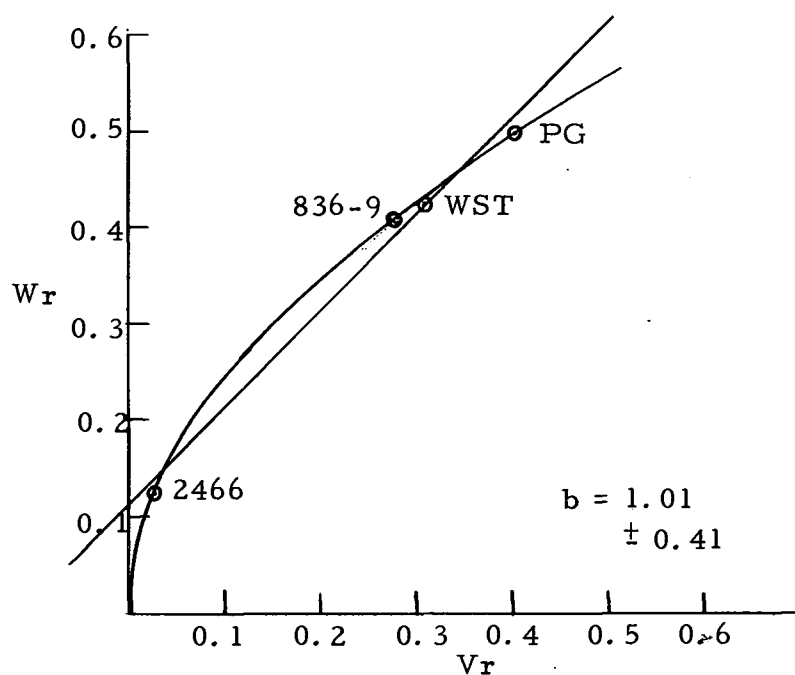


Figure 16. ( $W_r$ ,  $V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from number of internodes in the central stem in the field diallel. Ninety-five percent confidence limits of  $b$  are given.

Mean Internode Length. Observation of parents and progeny in the greenhouse and field confirmed the finding made in preliminary work that internode length, in contrast to internode number, is very sensitive to environmental influence. From Table 7 it can be seen that mean internode length was three- to five-fold greater in the greenhouse than in the field. Changing field environment, too, had a very marked influence; closer spacing increased length at both times of planting. Further, internode length at both spacings in the late June planting was much greater than in the mid-May planting. Mean internode length at close spacing in the late planting exceeded that at the wide spacing in the early planting by approximately two-fold.

Progeny differences in response under greenhouse and field environments may be seen in Table 15. The  $F_1$  of crosses between true and derived bush varieties exhibited positive heterosis in the greenhouse, while the  $F_1$  from crosses between true and between derived bush varieties approximated the midparent. Conversely, results in the field point to an inconsistency in the behavior of the  $F_1$  over the several types of matings. Crosses between true and derived bushes fell closer to the midparent with heterosis seen only among those involving 836-9 as a parent. The  $F_1$  of crosses between true bush varieties and between derived bush varieties

exhibited positive and negative heterosis, respectively.

According to Figure 17 the  $F_2$  depression for mean internode length in crosses involving PG and 836-9 is not great. It can be seen from Table 15 that although the  $F_1$  mean of 836-9 x PG and its reciprocal exceeded 836-9, the taller parent, by approximately 18 percent, the depression of the  $F_2$  was approximately three percent. Field observation during the growing season had indicated that  $F_2$  plants of these crosses were as vigorous as the  $F_1$ .

From analysis of the  $F_1$  and  $F_2$  diallel tables it could not be concluded that regression of  $W_r$  on  $V_r$  was present at the five percent level of significance (Figure 18). Removal of each parent in turn followed by analysis of the resulting  $3 \times 3$  tables revealed that the deletion of array 836-9 was most effective on the ( $W_r$ ,  $V_r$ ) graph and that it is the parent likely causing non-significance of regression (Figure 19). The remaining three points fall very near or on the line of regression, particularly in the  $F_1$ . Moreover, the regression line in Figure 19 intersects the  $V_r$  axis very close to the origin since, as might be expected from Table 15, the removal of 836-9 has carried with it most of the heterotic effects.

On both ( $W_r$ ,  $V_r$ ) graphs, before and after the deletion of 836-9, it is strongly suggested that PG, the short-internode parent, possesses the recessive alleles conditioning internode length.

Similarly, points representing 836-9, 2466, and WST cluster near the lower limit of the regression line and are, therefore, thought to possess a greater proportion of dominant alleles. In the field major genetic differences appear to separate PG from the other three parents, while in the greenhouse there is a greater tendency for PG and WST to behave alike.

In the greenhouse the relationship between the  $F_1$  and the mid-parent suggests, however, that the shorter mean internode length of WST is also recessive and, therefore, that both PG and WST are recessive in crosses with the derived bush varieties (Table 15 and Appendix Table 44). Differences in mean internode length between WST and 2466 are great in the greenhouse but are not consistent in the field; hence, behavior of this character in the field in crosses between these two varieties becomes distorted.



Table 15. Deviation of the  $F_1$  from the mean midparent and beyond the extreme parent for mean length of central stem internodes in the greenhouse and field diallels, and  $F_2$  depression in the field diallel.

Cross	Percent deviation of the $F_1$ from the mean midparent		Percent deviation of the $F_1$ beyond the extreme parent		Percent $F_2$ depression
	Greenhouse	Field	Greenhouse	Field	Field
WST x 836-9	31.6	10.8	5.6	5.8	6.1
WST x 2466	16.7	- 4.2	-----	-----	- 2.1
2466 x WST	48.6	- 6.2	9.3	-----	- 1.7
WST x PG	- 3.4	14.5	-----	3.3	4.0
836-9 x 2466	- 3.4	-10.5	-----	- 7.1	- 5.1
836-9 x PG	39.9	36.0	18.5	17.9	3.4
2466 x PG	48.0	12.0	14.0	-----	- 6.2
Mean	24.6	8.0			0.0

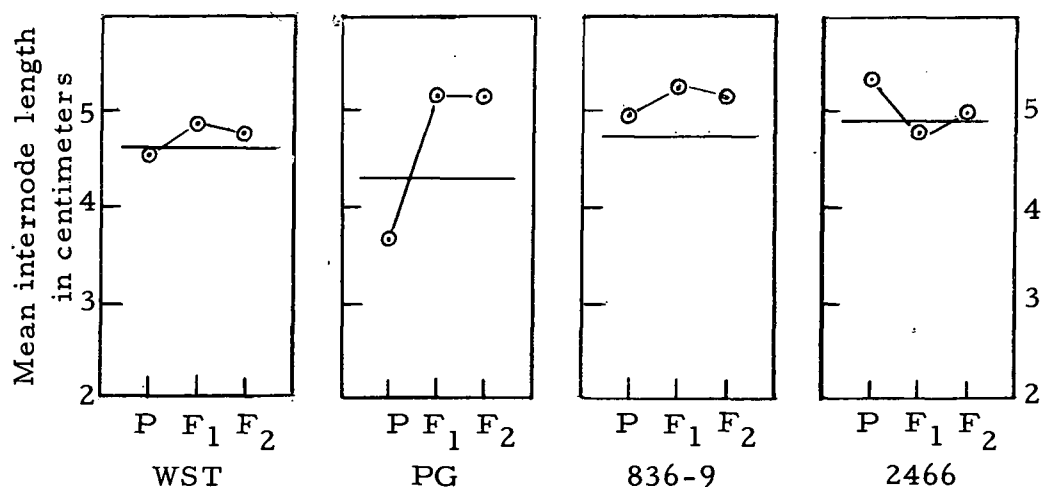


Figure 17. Graphic comparison of the generations for mean internode length composited across environments of the field diallel. The mean midparent values are shown by horizontal lines.

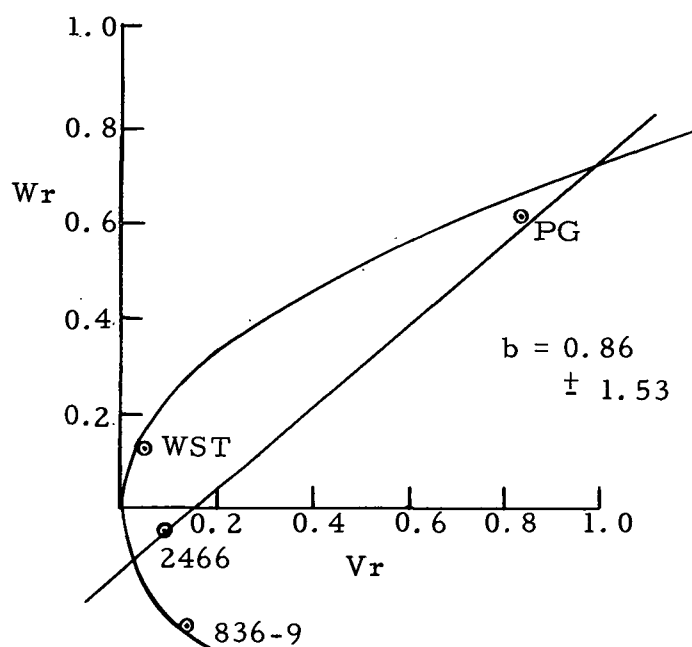
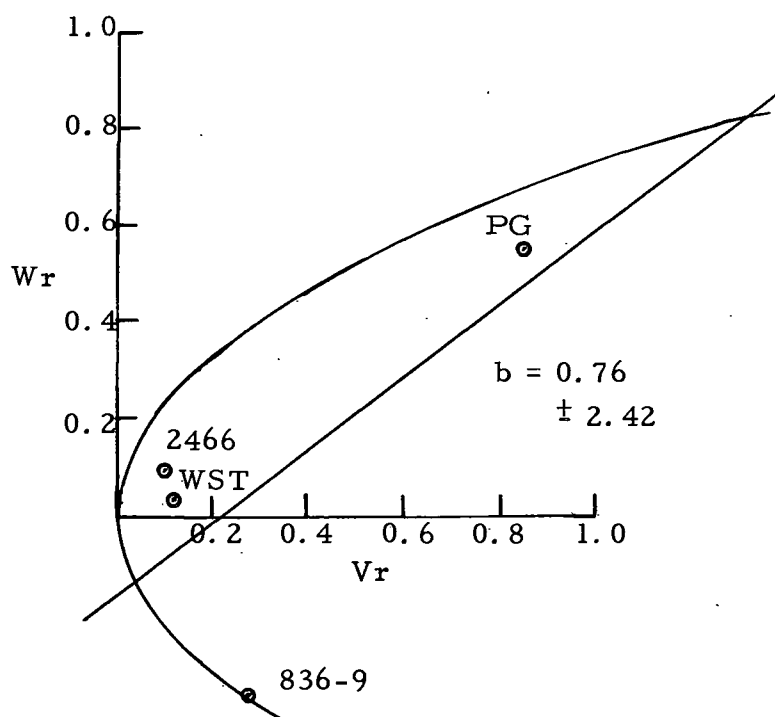


Figure 18. ( $W_r, V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from mean-internode-length data from the field diallel. Ninety-five percent confidence limits of  $b$  are given.

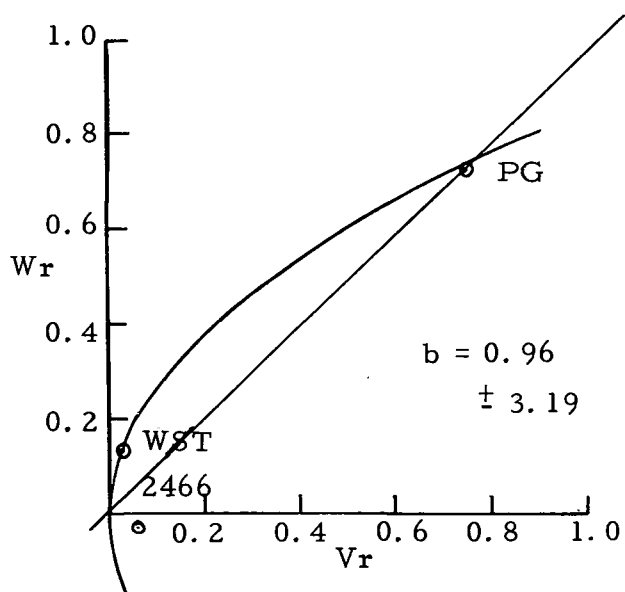
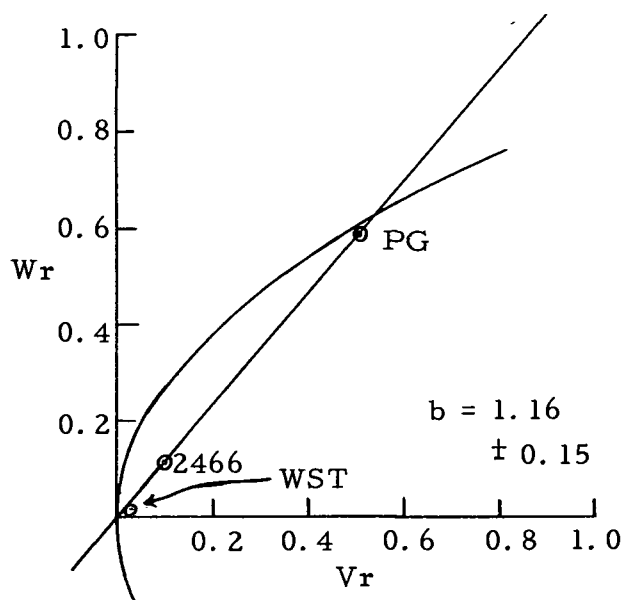


Figure 19. ( $W_r, V_r$ ) graphs of the  $F_1$  (Top) and  $F_2$  (Bottom) calculated from mean-internode-length data from the field diallel with parental array 836-9 omitted. Ninety-five per-cent confidence limits of  $b$  are given.

### Character Correlations

The character associations as summarized by the correlation coefficients presented in Table 16 reflect the differential behavior of the various characters in the several environmental regimes and in the parental,  $F_1$ , and  $F_2$  generations.

Habit versus Characters Expressing Plant Elongation. Since taller, longer plants tended to receive lower ratings, habit tended to be negatively correlated with both plant length and mean internode length at maturity and with plant height at 30 days after emergence. For plant height and length, an overall negative association with growth habit was evident only in the  $F_1$  and  $F_2$  populations.

It should be pointed out that a completely linear relationship probably did not exist between habit and characters measuring elongation in that an intermediate height and length appeared to be optimum for more desirable growth habit. Progressively taller and longer plants, as well as progressively shorter plants, received lower habit ratings. The number of plants considered as falling in to the "short" category was relatively small, however.

#### Habit versus other Characters

1. Number of Internodes. Habit was positively correlated

with number of internodes in the parental population in all four field environments. Generally, plants with a greater number of internodes in the central stem received a higher habit rating.

2. Number of Branches. In the  $F_1$  and  $F_2$ , plants with greater numbers of branches were given a lower habit rating, while in the parental population no overall association was noted. WST, a variety with few branches, and PG, a variety with a greater number of branches, both received relatively high habit ratings in the parental population. In the  $F_1$  and  $F_2$ , heavily branched plants appeared to be inferior in habit.

3. Pod Placement. As stated earlier, pod placement was a contributing factor in growth habit. It is not surprising, therefore, to find that these two characters were highly associated in all three generations.

Characters Expressing Plant Elongation versus Characters other than Habit. A general tendency for a positive association between plant height at 30 days after emergence and both overall length and mean internode length at maturity was noted at both spacings in the early planting. Compared to the early planting, the improved growing conditions in the second planting were reflected in greater branch growth and greater elongation after the time of height measurement. Consequently, the comparatively greater

growth which followed height measurement may have acted to reduce the association between height and both plant length and mean internode length. As a group, however, these three characters all tended to express plant elongation and to behave similarly in their association with other characters.

1. Number of Internodes. Not unexpectedly, an overall tendency for a positive association was seen between number of internodes in the central stem and characters which might reflect internode number-- plant length and height. These associations were, however, more often present in the  $F_1$  and  $F_2$  populations than in the parents.

The high negative correlation evident between number of internodes and mean internode length at both spacings in the second planting was caused by the relatively greater elongation of internodes in 2466. Variety 2466 possessed fewer central stem internodes than the other parental varieties, but exhibited greater internode elongation under favorable conditions. Thus, at close spacing in the second planting, internode elongation was at a maximum and the negative association was highly significant.

2. Number of Branches. An overall tendency was evident for positive association between number of branches and the three characters which measured elongation. The association was more

often present (1) in the  $F_1$  and  $F_2$  than in the parental population, and (2) in both spacings of the early planting. In the early planting, plants which showed greater elongation, as reflected by greater height and internode length, also exhibited greater branching. This association was not evident under the more favorable growing conditions of the second planting. Although also showing some weakness in the second planting, the correlation of plant length and number of branches was more consistent over the generations and environments and suggests that more heavily branched plants are more likely to possess greater length.

3. Pod Placement. Plant height at 30 days after emergence and both plant length and mean internode length at maturity did not behave similarly in their association with pod placement. While no association was evident with height, a significant correlation between pod placement and plant length was seen in the  $F_1$  and  $F_2$  at both spacings of the second or later planting. A positive but less consistent tendency for association was seen between pod placement and mean internode length in the  $F_1$  and  $F_2$ . At close spacing in the second planting, however, a striking negative correlation was evident in the parent population and could be traced to the occurrence of very low placement on 2466, a variety which in this environment showed a very marked increase in mean internode length.

Number of Central Stem Internodes versus Number of

Branches. A highly significant, positive association was noted between number of internodes and number of branches. Within environments, this association seemed to be more consistently present in the close spacing of the first planting. More-heavily-branched plants in the second planting did not appear to possess a greater internode number in the central stem.

Number of Central Stem Internodes versus Pod Placement. A highly significant association was evident between internode number and pod placement throughout the environmental regimes where pod placement ratings were given. Since many of the pods which reach maturity by the time of harvest are set on racemes from the central stem, higher pod placement is highly dependent upon a greater number of internodes in the central stem. The initial set of pods was noted to occur on racemes from the third node in variety 2466 and from the fourth or higher nodes in the other varieties.

Number of Branches versus Pod Placement. No consistent association was noted between branching and pod placement. From general observation it appeared that many of the branches, especially in the derived bush varieties, did not possess mature pods at harvest.



Table 16. Simple correlation coefficients for character associations at early and late planting and close and wide spacing in the field.<sup>v</sup>

Character pair <sup>u</sup>	Parents					F <sub>1</sub>					F <sub>2</sub>				
	Early Close	Early Wide	Late Close	Late Wide	Com-posite	Early Close	Early Wide	Late Close	Late Wide	Com-posite	Early Close	Early Wide	Late Close	Late Wide	Com-posite
1, 2	-.29	-.05	.56*	-.10	.01	.14	.06	.04	-.04	-.31**	-.56**	-.38**	-.21	.06	-.38**
1, 3	.31	.70**	.37*	.08	.58**	.69**	.29	.02	-.10	.44**	.54**	.72**	-.14	-.03	.46**
1, 4	.01	.39	.41	-.21	.14	.55**	.15	.23	-.13	.34**	.15	.26	-.21	.01	.28**
1, 5	.47	.53*	-.24	.12	.24	.63**	.40**	-.03	-.02	.34**	.42**	.67**	-.05	.06	.36**
1, 6	.71**	.76**	-.39	-.32	.24	.78**	.57**	-.03	-.21	.32**	.67**	.71**	.13	.06	.39**
1, 7			.40	-.27	-.08			.18	-.08	.03			-.14	.08	-.04
2, 3	.56*	.49	-.28	.08	-.09	.45**	.29**	-.19	-.18	-.31**	-.25	-.04	-.08	.09	-.44**
2, 4	.79**	.83**	.70**	.78**	.50**	.71**	.46**	.40**	.36*	.12	.30*	.32*	.54**	.72**	.09
2, 5	.32	.53*	-.44	-.07	-.01	.38*	.14	-.54**	-.37*	-.29**	-.26	-.04	-.52**	.02	-.31**
2, 6	.07	.14	-.85**	-.33	-.40**	.31*	.20	-.37*	-.13	-.31**	-.36*	-.25	-.70**	-.27	-.48**
2, 7			.78**	.81**	.75**			.33*	.35*	.31**			.59**	.73**	.58**
3, 4	.60*	.72**	.03	.27	.64**	.78**	.30*	.27	.44**	.66**	.62**	.63**	.54**	.39**	.70**
3, 5	.45	.68**	.20	.17	.57**	.83**	.75**	.28	.71**	.73**	.85**	.85**	.51**	.69**	.64**
3, 6	.56*	.72**	.26	.13	.64**	.82**	.28	.41**	.29*	.65**	.75**	.80**	.31*	.23	.64**
3, 7			-.14	.41	.22			.36*	.36*	.35**			.47**	.47**	.38**
4, 5	.47	.73**	.08	.38	.51**	.69**	.29	-.17	.54**	.47**	.68**	.76**	.01	.43**	.48**
4, 6	.37	.45	-.88**	-.50*	.12	.74**	.77**	.40**	.29*	.61**	.42**	.60**	-.29*	.06	.41**
4, 7			.77**	.86**	.79**			.75**	.72**	.65**			.80**	.86**	.74**
5, 6	.50*	.28	.10	-.61*	.16	.63**	.37*	.10	.43**	.15*	.54**	.74**	.28	.28	.07
5, 7			-.30	.11	-.24			-.19	.41**	-.17			-.01	.41**	-.28**
6, 7			-.89**	-.13	-.29			.43**	.20	.47**			-.24	.13	.34**

<sup>u</sup> The following number code for character designation has been used: (1) Plant height at 30 days after emergence (2) Growth habit (3) Plant length (4) Number of central stem internodes (5) Number of branches (6) Mean length of central stem internodes (7) Pod placement.

<sup>v</sup> "n" for the various comparisons is as follows:

Parents	16;	Composite	64
F <sub>1</sub>	48;	"	192
F <sub>2</sub>	48;	"	192

For associations including the character, pod placement: Parents, F<sub>1</sub>, and F<sub>2</sub> ---32; Composite ---96

\* and \*\* The value for "r" is significant at the five and one percent levels, respectively.

### Association of Pod Color and Morphological Characters

F<sub>2</sub> populations derived from PG showed segregation for the monogenically controlled character, pod color. Plants were classed as "wax-" or green-podded and chi-square analysis for degree of association was performed on contingency tables of color versus each of the several quantitatively inherited morphological characters. These analyses, summarized in Table 17 and presented in more detail in Appendix Tables 45 through 53, revealed several interesting associations which will be discussed in turn. Perhaps foremost among these was the general indication of a higher probability of association in the F<sub>2</sub> progeny of crosses of PG with WST.

Growth Habit. The results of analysis indicate that an association exists between pod color and plant habit in two of the three families segregating for color (Table 17 and Appendix Table 45). In these two families -- WST x PG and 2466 x PG -- wax plants tended to resemble their wax-podded parent more closely than the green-podded parent. Thus, from an examination of means in Table 17 it can be seen that in the F<sub>2</sub> of WST x PG wax segregates resembled the relatively inferior parent, PG, in growth habit. Wax segregates in the cross 2466 x PG also resembled PG, which in this case was the relatively superior parent. Although it is suggested

from Table 17 that the mean habit of wax segregates in the  $F_2$  of 836-9 x PG also appeared to resemble PG, the superior parent, no association could be detected upon analysis.

Number of Central Stem Internodes. The likelihood of association between pod color and number of internodes does not appear to be great from the sample of data analyzed. While association was significant at the five percent level in the cross 836-9 x PG, the probability of association was smaller in the other two  $F_2$  families analyzed (Table 17 and Appendix Table 46).

Internode Length. In all three crosses a highly significant association was detected between pod color and the length of the second and third internodes (Table 17 and Appendix Tables 47 and 48). Chi-square analysis for mean internode length reflected this association with, however, reduced probability of association seen in the cross 836-9 x PG (Table 17 and Appendix Table 49). Table 17 shows that wax-podded segregates in all crosses tended to have shorter internode length.

Plant Length and Height. Pod color appeared to be associated with both plant height at 30 days after emergence and plant length at maturity (Table 17 and Appendix Tables 50 and 51), although the probability of association was greater in the progeny of WST x PG than in the progeny of crosses of PG with the two

derived bushes. The means listed in Table 17, together with the illustration of  $F_2$  segregates in Appendix Figure 37 (Bottom), show the relatively shorter, more compact features of the wax segregates.

Number of Branches. While the means for wax- and green-podded segregates consistently suggest that wax segregates resemble the more heavily branched and wax-podded parent, PG, the results of analysis indicated that the probability of real association was high only in the  $F_2$  of WST x PG (Table 17 and Appendix Table 52). Considering all three crosses it is likely, however, that some association does exist between number of branches and pod color.

Pod Placement. Mean values indicated that wax-podded segregates in all three families possessed lower pod placement than their green-podded sibs (Table 17). The results of chi-square analysis, as seen in Table 17 and Appendix Table 53, substantiated this trend strongly in the cross WST x PG, to a lesser extent in 836-9 x PG, and offered no support in 2466 x PG.

Table 17. Mean and chi-square probability values for the association of pod color and morphological characters in F<sub>2</sub> families.

F <sub>2</sub> family	Growth habit	Number of internodes	Length of second internode	Length of third internode	Mean internode length	Plant length <sup>v</sup>	Plant height <sup>u</sup>	Number of branches	Pod Placement
WST x PG	<.01	.50-.30	<.01	<.01	<.01	<.01	<.01	.05-.02	<.01
836-9 x PG	.50-.30	.05-.02	<.01	<.01	.30-.20	.05-.02	.20-.10	.30-.20	.20-.10
2466 x PG	<.01	.20-.10	<.01	<.01	.02-.01	.05-.02	.20-.10	.20-.10	.80-.70

Mean Values Pertinent to the Above Table

WST x PG	W* 6.46	5.56	1.39	1.88	3.70	51.07	25.97	12.60	5.98
	G 6.56	5.69	1.71	2.28	4.47	55.26	29.97	10.86	6.98
836-9 x PG	W 4.21	5.57	1.26	2.13	4.33	53.60	32.80	13.93	6.40
	G 4.14	5.48	1.69	2.67	4.89	58.67	35.42	13.15	6.66
2466 x PG	W 3.78	4.57	1.39	2.86	4.31	53.18	31.09	12.75	5.26
	G 3.28	4.41	1.84	3.55	4.91	59.83	30.58	11.81	5.51

\* "Wax" is abbreviated as W and "Green" as G.

<sup>u</sup> Height of plant was measured from the ground level to the outstretched tip of the terminal growing point at approximately 30 days after plant emergence.

<sup>v</sup> Length of the pulled plant at pod maturity was measured from the cotyledonary node to the tip of the most terminal growing point.

### Behavior of $F_3$ and $F_4$ Families

As shown in Table 18, comparison of field grown  $F_3$  and  $F_4$  populations derived from single-pod  $F_2$  selections of crosses between WST and various derived bush lines revealed little gain in gross habit desirability during the one generation of selection in the greenhouse. However, it should be emphasized that at the time of selection further elimination based upon pod qualities was made and may have acted to remove part of any gain achieved in habit. From Table 19 it can be seen that for growth habit the correlation between the greenhouse and the field varied with the parentage. Progeny derived from 682-1328, 682-2388 and a massed population of improved lines from the seventh backcross to FM-1 appeared, in terms of growth habit, to be closely associated in the greenhouse and field.

From Table 18 it can be seen that selection for shorter plant height was effective. Plants short under greenhouse conditions are very likely to be short in the field. Results of the observation of several selected intra-family extremes for habit and height, as reported in Table 20, lend further support to this finding. Differences in growth habit were, however, not maintained from these  $F_3$  intra-family extremes to their  $F_4$  progeny in the field.

Table 18. Growth habit and plant height comparisons of field-grown  $F_3$  and  $F_4$  families derived from single-pod  $F_2$  selections.<sup>u</sup>

Origin	Number of families	Growth habit (0-9 rating)			Plant height in inches		
		Mean $F_3$	Mean $F_4$	Paired t	Mean $F_3$	Mean $F_4$	Paired t
Many Blue Lake Lines x WST	87	6.75	6.73	-0.4059	14.05	12.32	-3.7655**
Lines of 682 x WST	33	7.26	6.90	-0.5944	14.72	12.58	-2.6429**
WST x Lines of B-260	21	6.66	6.52	-0.5639	13.58	11.45	-2.4788*
BC-7(FM-1) x WST	11	6.78	6.90	0.4857	15.44	13.33	-2.6934*
BC-7(637) x WST	9	6.44	6.91	1.3021	11.52	9.60	-4.3590**

\* and \*\* The value for "t" is significant at the five and one percent levels, respectively.

<sup>u</sup> Selection in the  $F_3$  generation occurred in the greenhouse and remnant  $F_3$  seed was used in the field.

Table 19. Growth habit correlation of greenhouse- and field-grown  $F_3$  populations derived from single-pod  $F_2$  selections.

Origin	Number of families	r value
682-1328 x WST	39	.3163*
682-2388 x WST	68	.4395**
WST x 682-2475	12	.4477
WST x Lines of B-260	81	.0937
BC-7 (FM-1) x WST	49	.4500**
BC-7(637) x WST	51	.2177

\* and \*\* The value for "r" is significant at the five and one percent levels, respectively.

Table 20. Comparison of field-grown  $F_4$  derivatives with the greenhouse-grown,  $F_3$  intra-family extremes from which they were obtained.

Origin	Growth habit (0-9)				Plant height in inches			
	Tall*		Short		Tall		Short	
	$F_3$	$F_4$	$F_3$	$F_4$	$F_3$	$F_4$	$F_3$	$F_4$
	Green-house	Field	Green-house	Field	Green-house	Field	Green-house	Field
WST x B-260-5Aa	6.00	6.67	7.00	6.33	36.0	14.7	14.0	11.3
WST x 682-2475	5.00	6.00	8.00	5.00	40.0	15.0	18.0	10.3
BC-7(FM-1) x WST	6.00	7.00	8.00	6.50	29.0	13.0	19.0	10.0
682-2388 x WST	6.00	4.50	7.00	5.30	36.0	21.0	21.0	15.3
2195 x WST	6.00	5.80	8.00	6.00	31.0	12.0	15.0	15.0
T x 682-1327-1								

\* The two single-plant extremes detected in the greenhouse for each of the five  $F_3$  families were designated as "tall" and "short".



## DISCUSSION AND CONCLUSIONS

Environmental Influence on Character Expression

The plant breeder is constantly faced with the need to evaluate plant populations in environmental regimes which vary with time and location. Expression of the genotype varies more or less with these changes and may render accurate evaluation for wide adaptability difficult.

Growth habit and related morphological characters in the bush bean, and particularly in bushes derived from the Blue Lake pole bean, appear to be especially sensitive to environmental change. In the field, wide variation in character expression was noted in four environments defined in terms of two in-row plant spacings (two and six inches) at each of two times of planting (May 15 and June 30). Closer plant spacing resulted in greater elongation and fewer branches. Development was slowed during the cool weather which followed the first planting and plants of all varieties were shorter, more compact, and relatively erect in stature.

Hess (6, p. 12-50) was able to show marked differential response under field and winter greenhouse conditions for two parents (one true and one derived bush) and their  $F_2$  progeny. The two parent varieties used reversed their relative ranking for central

stem length from the greenhouse to the field and, in the greenhouse, failed to show the difference in degree of branching which was so evident in the field. In the present study the effects of the environmental change from greenhouse to field were somewhat less drastic. Although greenhouse grown plants were taller, less heavily branched, and weaker than those grown in the field, the differential varietal response between the two environments, while noticeable, was usually not of sufficient magnitude to upset the ranking of the four parent varieties for the several characters observed. Furthermore, differences in degree of branching were noted in both the field and greenhouse. These results indicate that the varietal differences which occur for stem length and for number of branches may remain sufficiently stable to environmental change to permit effective selection in the greenhouse.

Variety 2466, however, resembled one variety (1356 Short) used by Hess, in showing marked differential response for stem elongation. In the present study 2466 showed greater elongation in the greenhouse than the other parents, while in the early planting in the field this variety tended to be shorter, particularly at wide spacing. In the later planting 2466 exhibited greater elongation and more closely resembled its performance in the greenhouse. Conversely, variety 836-9 and the true bush varieties WST and PG

were more stable across environments.

Further illustration of the overall sensitivity of plant growth and development to environment was emphasized by changes in character correlations from environment to environment (Table 16). Time of planting had greater influence, as judged by changes in these correlations, than plant spacing. Number of branches was more often correlated with mean internode length, internode number, and plant length in the first planting than in the second. Plant height was associated with mean internode length only in the first planting and a similar trend of association was seen with plant length.

The relative instability of Blue Lake derived bushes to environmental change was evident throughout the investigation and was dramatically illustrated in the shading experiment. The true bush variety, WST, showed little response to five-day periods of shade which acted to increase stem and branch elongation in derived bushes when applied at a critical stage of growth. This critical stage seemed to coincide approximately with the beginning of expansion of the second trifoliate leaf, that is, just prior to the period of normally rapid stem elongation. In showing markedly greater elongation derived bushes behaved in a manner similar to that described by Havis (5, p. 451-454) for bush lima beans covered with

cheese cloth. Such differential behavior highlights the difficulty involved in securing Blue Lake derived bushes which are sufficiently well adapted to give consistent performance from year to year and from location to location for growth habit and possibly for other characters as well.

Rather heavy selection pressure for desirable habit probably is applied under winter conditions in the greenhouse. Judging from the behavior of WST, plants which definitely possess superior habit in the greenhouse are likely to be superior in the field. In addition, stem elongation, an important consideration in habit evaluation, is greatly promoted in the greenhouse and plants which are short in this environment can be expected to be short --occasionally too short -- in the field. Examination of  $F_3$  families and of their  $F_4$  progeny selected in the greenhouse revealed that selection for height in this environment was effective.

#### Gene Action Involved in Character Expression

In the greenhouse the results of the evaluation of the four parents and of the  $F_1$  plants from the crosses among them leads to the broad, general conclusion that the genes conditioning the expression of the characters measured or rated in this study are, on the average, recessive in the true bushes. This is apparent for growth habit,

plant height at 30 days after emergence, plant length, and number of internodes and less obvious for branching. In the field, evaluation of the parents and the  $F_1$  and  $F_2$  generations confirmed this interpretation for habit and number of internodes, but gave only a partial confirmation for the other characters. For plant height, length, and mean internode length the rather consistent occurrence of heterosis and the occasional change in ranking between true and derived bushes over the field environments act to render detailed interpretation of dominance and recessiveness of questionable value.

Although the true bush varieties in the field appeared to contain more of the recessive alleles for plant height (as measured at 30 days after plant emergence), the presence of only small differences among the parents and the interaction effects contributed by 2466 act to make interpretation less meaningful for this character. For plant length, measured at maturity, the presence of both strong heterosis and noticeable genotype x environmental interaction superimposed on the small differences among the parents in the field probably again does not justify further detail in interpretation of results. The four parents do not maintain a consistent relationship over the several environments of the field. A similar problem is encountered in studying mean internode length. With the exception of crosses between WST and 2466, the true bushes do, however,

appear to contain more of the recessive alleles.

With regard to branching, the true bushes again did not behave alike in crosses with the derived bushes. The low branch number of WST and the high branch number of PG appear to behave as recessively and dominantly inherited characters, respectively.

The striking heterosis consistently observed in both the greenhouse and field for plant height, length, and mean internode length in progeny of crosses between true and derived bushes which have essentially the Blue-Lake-pole genotype is probably not in itself a new finding. Although the  $F_1$  generation was not used in the study conducted by Hess (6, p. 1-67), the approximation of the taller parent by the  $F_2$  indicated that such heterosis probably existed in the  $F_1$ . Malinowski (13, p. 96-110), working with two apparently true bush varieties had also observed heterosis for the above characters and for degree of branching as well. In the present study heterosis for branching was, however, not consistent but in the field was present in crosses between WST and the derived bushes and did not appear consistently in crosses between PG and the derived bushes. In the greenhouse a tendency toward negative heterosis<sup>1</sup> for number of branches existed in the  $F_1$  generation.

In crosses between 2466 and WST reciprocal differences were

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<sup>1</sup> Negative heterosis as used in this discussion is heterosis such that the  $F_1$  falls below the smaller or lesser of the two parents.

evident for plant height, length, and mean internode length in  $F_1$  progeny grown in the greenhouse. Progeny from the cross 2466 x WST showed strong heterosis while progeny from the reciprocal of this cross approached the midparent for these characters. Except possibly for plant height, these maternal effects were not evident in the field and progeny of crosses made in either direction between these two parents showed heterosis.

From analysis of the  $F_1$  and  $F_2$  generations of crosses between true and derived bush varieties it can be concluded that (1) habit per se is continuously variable, (2) additive effects predominate in the net effect of gene action in habit expression, and (3) selection progress for habit alone, possibly without regard to pod characters, could be made rather quickly. Observation of progeny from crosses among the four parents indicated that the net effect of the genes conditioning habit is one of partial dominance and one in which desirable, upright habit tends to be recessive. In the population studied, genetic differences between true and derived bushes were greater than those within each of these two types.

Exact duplication of the recessive, superior phenotype was not seen in any of the  $F_2$  populations, and crosses, in the  $F_2$  generation, differed in their approach toward the parental extremes. Comparing  $F_2$  families a somewhat closer approximation of the

superior parent was seen in crosses involving WST and the derived bushes, particularly 836-9.

It was interesting to pursue further the differential behavior of 836-9 and 2466, with regard to habit, in crosses with PG and WST. In the field,  $F_1$  plants from crosses between WST and 2466 and between PG and 836-9 showed stronger dominance of poor habit than the other two possible crosses between these true and derived bushes (Table 9). In the  $F_1$  of crosses between WST and 2466, great branch vigor accompanied by a low number of central stem internodes and low pod placement were important in accounting for poor habit. Heterosis for mean internode length and branch elongation (both of which are also reflected in plant height and length) appeared to be a primary manifestation of inferior habit in the  $F_1$  of crosses between PG and 836-9 (Table 15). These findings suggest that while the graphic method of diallel analysis may yield an appraisal of overall effects which may then be interpreted in terms of "gene" action, it may mask revealing highlights seen through the detailed study of individual crosses.

The recessive behavior of genes conditioning desirable growth habit is not surprising when one examines several of the morphological characters which are related to habit. Among these, varying degrees of non-additive effects, such as, dominance,



heterosis, and possibly non-allelic interaction were found for plant height, length, mean internode length and branching. Since excessive elongation and branching are not physically compatible with acceptable bush habit, dominance or heterosis in these characters is reflected as recessiveness in the inheritance of gross habit of growth. The rating of growth habit is of course an all-inclusive evaluation and considers, in addition to those morphological characters separately observed in the present study, all other factors which influence habit. Some of these may be quite intangible, and others readily measurable. The visual effects of possible heritable differences in stem fiber and auxin level may, for example, be included in habit rating. The separate examination of such characters might also prove useful in further attempts to illuminate causes behind habit differences.

The placement of pods upon the plant is a difficult characteristic to describe and evaluate and for this reason a rating scheme was adopted in the present investigation. Since a large proportion of the pod load usable at the time of harvest seems to be set on racemes from the central stem, it is not surprising to find that pod placement and number of central stem internodes show a high positive association. Variety 2466, the parent with the fewest internodes, consistently had lower placement of pods even though this

variety, at close spacing in the second planting, averaged taller at 30 days after emergence (just prior to anthesis) than the other three varieties. The first two internodes of 2466 were quite shortened and the initial heavy pod set occurred on racemes from the third node (beginning with the cotyledonary node). Varieties 836-9, WST, and PG were fairly similar in possessing more central stem internodes and higher pod placement than 2466 and all three of these varieties appeared to contain a much larger proportion of the recessive alleles for number of stem internodes.

The net effect of the gene action conditioning pod placement and number of internodes seems to be one of partial dominance. PG contains a large proportion of the dominant alleles for pod placement (Figure 6), while 2466 contains a large proportion of the dominant alleles for number of central stem internodes (Figure 10). Variety 2466 is the low parent for both of these characters. The lower pod placement of 2466 is, therefore, inherited as a partially dominant character in crosses with WST and 836-9 and as a partially recessive character in crosses with PG (Table 10). Since in all crosses the lower mean internode number of 2466 appears to be inherited as a partially dominant character, one would expect lower pod placement in the progeny of crosses involving this variety. However, the greater mean internode length of 2466 in crosses with PG shows,

in the later planting, a high degree of dominance (Table 15), which would reduce the correlation between pod placement and internode number.

These findings, with regard to pod placement and internode number, point to the general desirability of eliminating those plants possessing fewer than four central stem internodes. Low internode number is highly associated with poor habit as well as with low pod placement. Since internode number under winter conditions in the greenhouse gives a good indication of internode number in the field, such elimination can, in a practical sense, be accomplished in either of these two environments.

#### Association of Pod Color and Morphological Characters

From the results of chi-square analysis the presence of association between pod color and various morphological characters is evident (Table 17). Wax-podded  $F_2$  segregates resembled PG, the wax-podded parent, in appearing to be, on the average, shorter and more heavily branched and to have more central stem internodes. Gross habit of growth of wax segregates also tended to resemble PG.

Whether these associations are due to linkage or pleiotropy cannot be determined from  $F_2$  data alone. It would be tempting to postulate that a linked association exists and that some of the

several to many genes influencing each morphological character are linked with the gene conditioning pod color. Micro-environmental effects, the segregation of other genes for these characters, and the breaking of linkage could act to produce the great within family variation exhibited among  $F_2$  wax segregates.

Except for number of internodes, the probability of association appeared to be higher, as a general rule, in crosses of PG with WST than with 836-9 or 2466. Both PG and WST are true bush types and between them, as compared to true versus derived bushes, a greater genome homology would not be unexpected. Thus, on the chromosome carrying the pod-color gene the magnitude of gene effects contributing to the expression of a particular morphological character may be more nearly the same between the two true bush varieties than between the true and derived bushes. Hence, the effects of linkage may be more noticeable in crosses between true bush varieties.

In comparing wax- versus green-podded progeny from 836-9 with those from 2466, wide variation in the probability of association of pod color with both growth habit and pod placement was apparent. Whether this discrepancy is due to different genetic constitutions of 2466 and 836-9 or is due to chance cannot be determined from the analysis.

Since only one wax-podded parent was used in the present investigation, caution should be used in predicting the universality of the association with pod color described here. The presence of these associations should be of considerable interest to bean breeders, however, and further testing of their validity by means of crosses between wax- and green-podded varieties representing considerable diversity for one or more of the morphological characters seems justified.

## SUMMARY OF CONCLUSIONS

1. Bush bean varieties derived from backcrossing to the Blue Lake FM-1 pole bean were more sensitive to environmental change than were true bush varieties.

- a. Derived bushes showed greater stem elongation and overall plant weakness under winter conditions in the greenhouse. In the field, shade imposed for a five-day period during or just prior to the time of normally rapid stem elongation caused greater elongation in derived bushes.
- b. In 1962, late June as opposed to mid-May planting in the field increased stem elongation, number of branches, number of central stem internodes and reduced habit desirability in true and derived bushes. At both times of planting, derived bushes showed relatively greater stem elongation at the two- as opposed to the six-inch in-row plant spacing.
- c. The number of central stem internodes increased from the earlier to the later planting but was not influenced by shade or spacing.

2. Under winter conditions in the greenhouse the performance

of the  $F_1$  progeny from crosses among the four varieties suggested that the two true bush varieties contain more of the recessive alleles for growth habit, plant length, mean internode length, number of central stem internodes, and number of branches (these characters were measured or rated at pod maturity). A similar conclusion was made for plant height (measured shortly prior to anthesis).

3. Under field conditions the existence of genotype x environmental interaction, in addition to the presence of smaller parental differences, rendered the possible recessiveness of alleles in the true bush varieties less evident except for growth habit and number of internodes. Varieties 836-9 and 2466, and particularly the latter, probably accounted for most of the genotype x environmental interaction.

4. In crosses with the two derived bushes the expression of high pod placement (studied only the late June field planting) in the two true bushes was conditioned by a preponderance of recessive alleles in one (WST) and by dominant alleles in another (PG).

5. However, in this population of four parental varieties the net effect of the gene action conditioning the expression of pod placement, as well as growth habit and number of central stem internodes, appeared to be largely additive in all of the environments considered.

6. Non-additive gene action was more important in the

expression of plant length, height, and mean internode length.

Striking heterosis was observed in both the greenhouse and field for these three characters.

7. Heterosis for number of branches was not consistent both with regard to parentage and to change in environment; a tendency toward heterosis existed in progeny of crosses between true and derived bush varieties in the field whereas in the greenhouse this was replaced by a tendency toward negative heterosis.

8. In the greenhouse, reciprocal differences for plant length, height, and mean internode length were seen in progeny of crosses between WST and 2466.  $F_1$  progeny of the cross WST x 2466 exhibited heterosis while  $F_1$  progeny of the reciprocal cross closely approached the midparent.

9. Both high pod placement and desirable growth habit were positively correlated with a greater number of central stem internodes.

- a. Internode number was more important than internode length in determining height of pod placement.
- b. Relatively more internode elongation occurred in low-internode-number plants grown under environmental conditions favorable for elongation; therefore, internode number was not always positively correlated with plant



length, height, or mean internode length.

10. Pod color, classified as "wax" or green, was found to be associated with growth habit, plant length, height, internode length, number of branches, and possibly with pod placement and number of central stem internodes. These associations were not entirely consistent over all  $F_2$  progenies but were somewhat more evident in crosses of PG with WST than with 836-9 or 2466, the two derived bushes.

## BIBLIOGRAPHY

1. Adams, M. W. and R. Duarte. The nature of heterosis for a complex trait in a field bean cross. *Crop Science* 1(5): 380. 1961.
2. Allard, R. W. Biometrical approach to plant breeding. In: *Genetics and plant breeding. Brookhaven Symposia in Biology Number 9.* Upton, New York, Brookhaven National Laboratory, 1956. p. 69-88.
3. Emerson, R. A. A genetic study of plant height in Phaseolus vulgaris. Lincoln, University of Nebraska, 1916. 73 p. (Nebraska. Agricultural Experiment Station. Research Bulletin no. 7)
4. Frazier, W. A., J. R. Baggett and W. A. Sistrunk. Transfer of certain Blue Lake pole bean pod characters to bush beans. *Proceedings of the American Society for Horticultural Science* 71:416-421. 1958.
5. Havis, Leon. Effects of certain environmental conditions upon the growth habit of the Henderson Bush Lima Bean. *Proceedings of the American Society for Horticultural Science* 29:451-454. 1932.
6. Hess, Wilford M. Inheritance of growth habit in bush bean, Phaseolus vulgaris L. Master's thesis. Corvallis, Oregon State University, 1960. 67 numb. leaves.
7. Hikida, H. R. Use of cellophane tape as an improved technique in crossing common bean, Phaseolus vulgaris. Annual report of the Bean Improvement Cooperative no. 4:15-16. Feb. 1961.
8. Jinks, J. L. and B. I. Hayman. The analysis of diallel crosses. *Maize Genetics Cooperation News Letter* no. 27:48-54. 1953.

9. Lamprecht, Herbert. Zur Genetik von Phaseolus vulgaris. X. Über Infloreszenztypen und ihre Vererbung. Hereditas 20:71-93. 1935.
10. \_\_\_\_\_ Die Artgrenze zwischen Phaseolus vulgaris L. und Multiflorus Lam. Hereditas 27:51-175. 1941.
11. Li, Jerome C. R. Introduction to statistical inference. Corvallis, Oregon. Edwards Bros., 1957. 553 p.
12. Malinowski, E. A peculiar case of heterosis in Phaseolus vulgaris. Verhandlungen des V. Internationalen Kongresses für Vererbungswissenschaft 2:1090-1093. 1927.
13. \_\_\_\_\_ Studies on hybrid vigor in Phaseolus vulgaris (L.) SAVI. Part 1. Vigorous sizes and photoperiodic response of the F<sub>1</sub> plants. Zeitschrift für induktive Abstammungs- und Vererbungslehre Bd. 70:96-124. 1935.
14. Nijdam, F. E. L'analyse morphologique des caractéristiques agricoles des variétés. Acta Botanica Neerlandica 4(3):452-459. 1955.
15. Norton, J. B. Inheritance of habit in the common bean. American Naturalist 49:547-561. 1915.
16. Snedecor, George W. Statistical methods. Ames, Iowa State College, 1955. 485 p.
17. Tschermak, E. von. Bastardierungsversuche an Leukojen, Erbsen, und Bohnen mit Rücksicht auf die Factorienlehre. Zeitschrift für induktive Abstammungs- und Vererbungslehre Bd. 7:81-234. 1912.
18. U.S. Weather Bureau. Climatological data. National summary 12:318, 375, 427. 1961.

## APPENDIX

Table 21. Analysis of variance for growth habit in the preliminary spacing experiment.

Source of Variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	9.75	4	2.4375	9.6573**
Spacing	9.66	2	4.8300	19.1363**
Variety	189.31	8	23.6638	93.7552**
S x V	35.67	16	2.2294	8.8328**
R x T	26.25	104	0.2524	
Total	270.64	134		

\*\* The value for "F" is significant at the one percent level.

Table 22. Analysis of variance for number of branches per plant in the preliminary spacing experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
---------------------	----------------	--------------------	-------------	---------

## ANALYZED AS A 2 x 6 FACTORIAL

Replication	51.34	4	12.8350	3.4154*
Spacing	769.70	1	769.7000	204.8164**
Variety	697.51	5	139.5020	37.1213**
S x V	68.33	5	13.6660	3.6365**
R x T	165.35	44	3.7580	
Total	1752.23	59		

## ANALYZED AS A 3 x 4 FACTORIAL

Replication	113.26	4	28.3150	5.9264**
Spacing	937.47	2	468.7350	98.1069**
Variety	139.38	3	46.4600	9.7241**
S x V	34.64	6	5.7733	1.2084
R x T	210.22	44	4.7778	
Total	1434.97	59		

\* and \*\* The value for "F" is significant at the five and one percent levels, respectively.



Figure 20. Unshaded (Top) and shaded (Bottom) plants of 949-1864-2-1M at the end of the five-day shade treatment which began at 14 days after plant emergence.

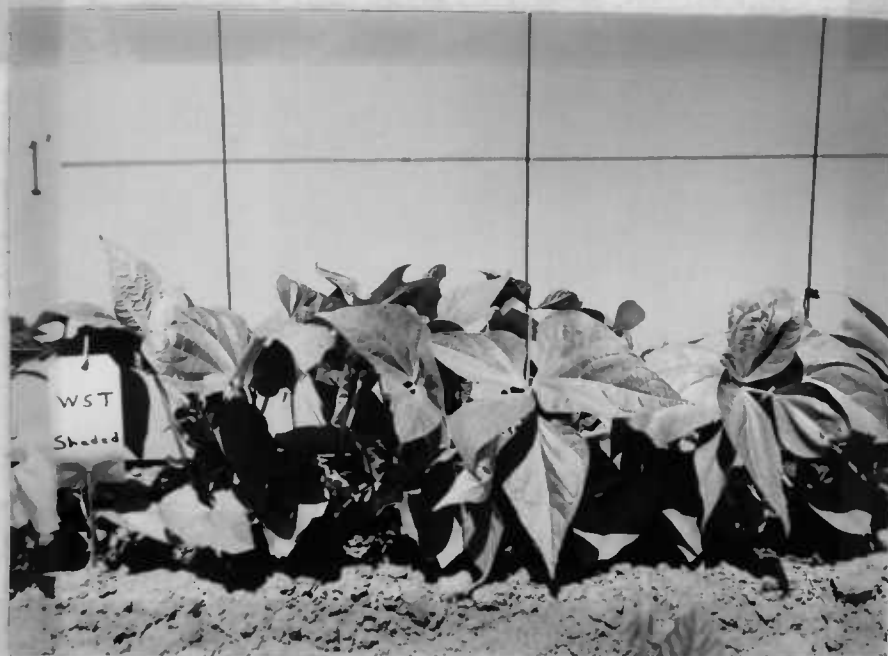


Figure 21. Unshaded (Top) and shaded (Bottom) plants of WST at the end of the five-day shade treatment which began at 14 days after plant emergence.

Table 23. Analysis of variance for growth habit in the shade experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	1. 8611	2	0. 93056	1. 4795
Time of Shading	15. 2778	7	2. 18254	3. 4807*
R x T (Error A)	8. 8056	14	0. 62897	
-----				
Variety	64. 1111	2	32. 05556	66. 8986**
V x T	7. 2222	14	0. 51587	1. 0766
Error B	15. 3333	32	0. 47917	
V x R				
V x R x T				
Total	112. 6111	71		

\* and \*\* The value for "F" is significant at the five and one per-cent levels, respectively.



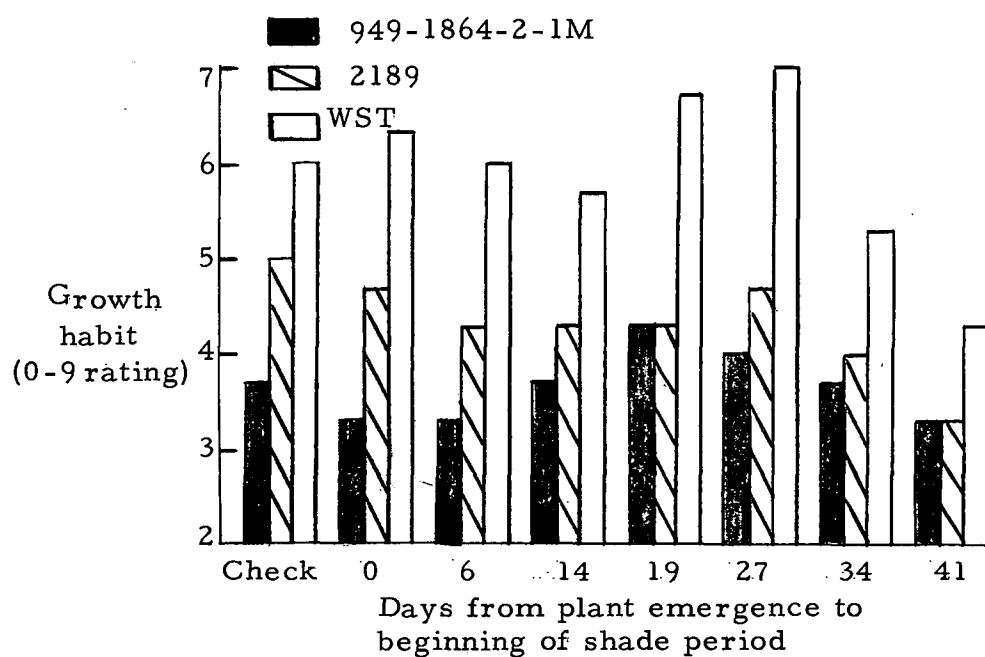


Figure 22. Graphic comparison of the influence of a five-day period of shade on growth habit.

Table 24. Analysis of variance for plant height in the shade experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	8. 27	2	4. 1350	14. 9509**
Time of Shading	93. 37	3	31. 1233	
R x T (Error A)	12. 49	6	2. 0817	
-----				
Variety	201. 48	2	100. 7400	109. 2743**
V x T	31. 75	6	5. 2917	5. 7400**
Error B	14. 75	16	0. 9219	
V x R				
V x R x T				
Total	362. 11	35		

\*\* The value for "F" is significant at the one percent level.

Table 25. Analysis of variance for plant length in the shade experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	5. 8675	2	2. 9338	4. 8371**
Time of Shading	211. 0416	6	35. 1736	
R x T (Error A)	87. 2601	12	7. 2717	
-----				
Variety	418. 2822	2	209. 1411	106. 7809**
V x T	79. 3524	12	6. 6127	3. 3762**
Error B	54. 8394	28	1. 9586	
V x R				
V x R x T				
Total	856. 6432	62		

\*\* The value for "F" is significant at the one percent level.

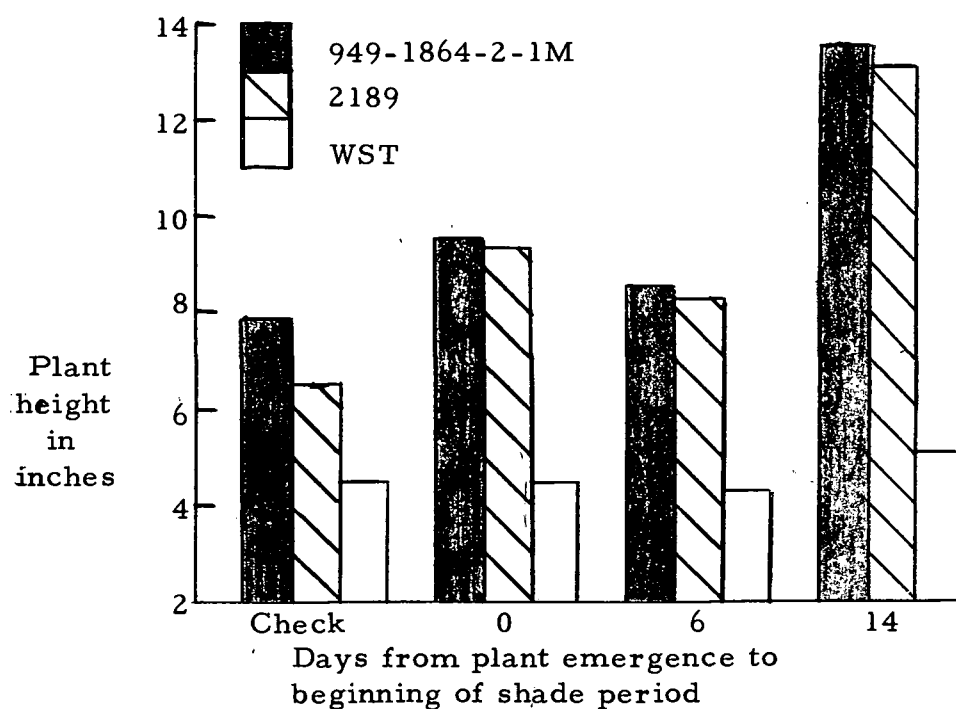


Figure 23. Graphic comparison of the influence of a five-day period of shade on height measured at 19 days after plant emergence.

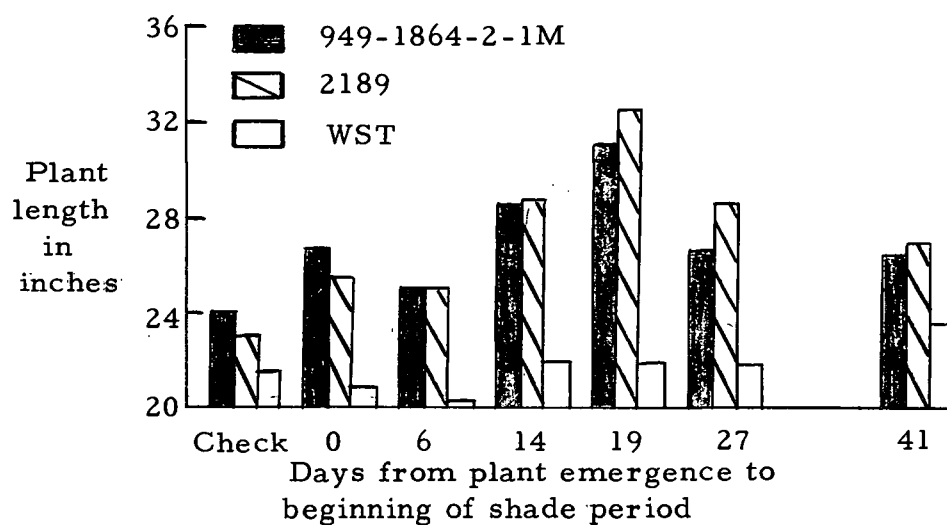


Figure 24. Graphic comparison of the influence of a five-day period of shade on plant length.

Table 26. Analysis of variance for mean internode length in the shade experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	0.3133	2	0.15665	
Time of Shading	3.8587	5	0.77174	6.0652**
R x T (Error A)	1.2724	10	0.12724	
-----				
Variety	9.3451	2	4.67255	65.3778**
V x T	2.6179	10	0.26179	3.6629**
Error B	1.7153	24	0.07147	
V x R				
V x R x T				
Total	19.1227	53		

\*\* The value for "F" is significant at the one percent level.

Table 27. Analysis of variance for number of central stem internodes in the shade experiment.

Source variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	0.00857	2	0.004285	
Time of Shading	0.17199	6	0.028665	
R x T (Error A)	0.59363	12	0.049469	
-----				
Variety	3.49240	2	1.746200	49.3276**
V x T	0.39650	12	0.033042	
Error B	0.99120	28	0.035400	
V x R				
V x R x T				
Total	5.65429	62		

\*\* The value for "F" is significant at the one percent level.

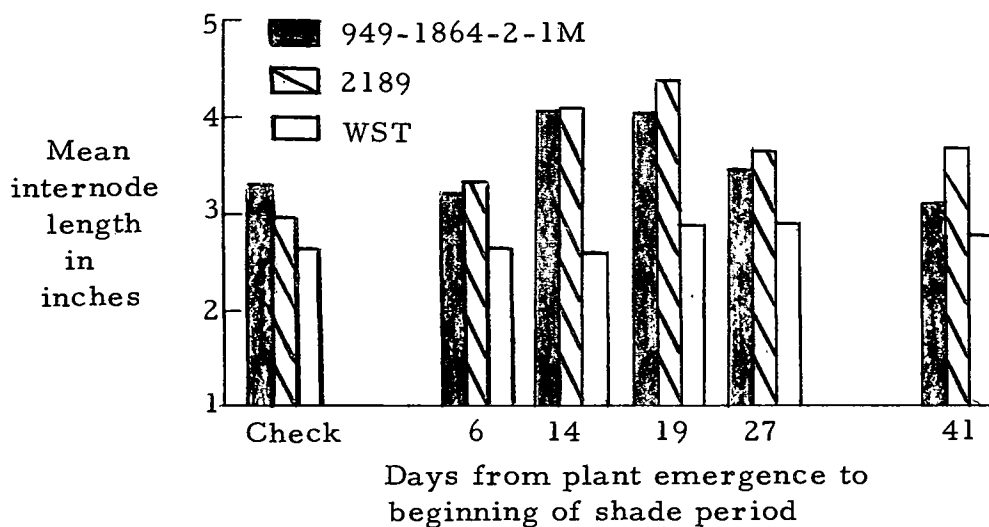


Figure 25. Graphic comparison of the influence of a five-day period of shade on the mean length of central stem internodes.

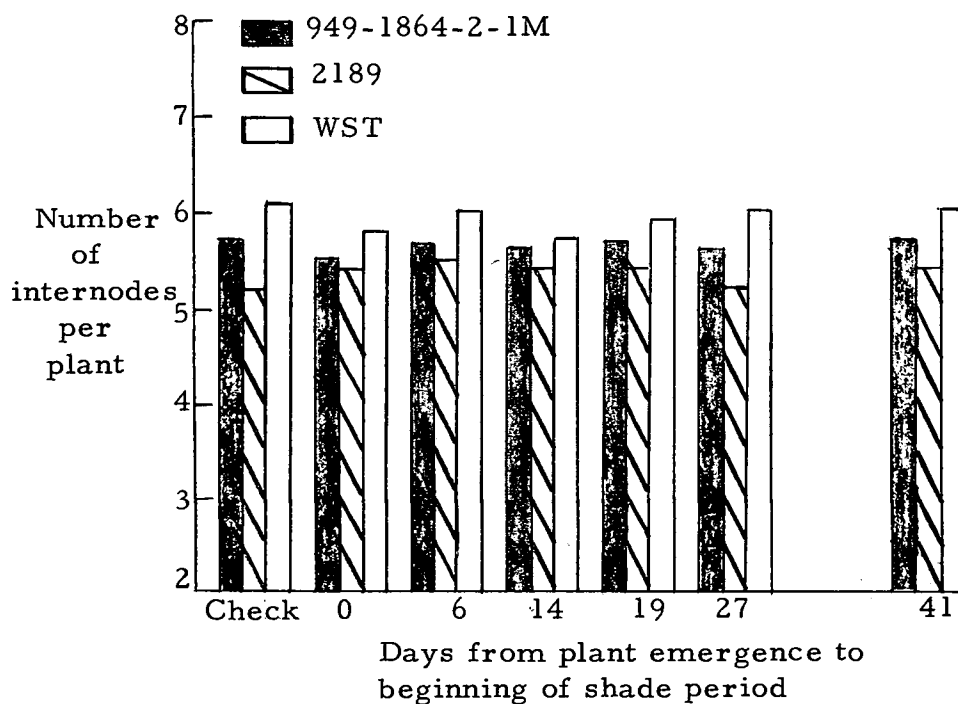


Figure 26. Graphic comparison of the influence of a five-day period of shade on the number of central stem internodes.

Table 28. Analysis of variance for length of the longest branch in the shade experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	1.583	2	0.7915	
Time of Shading	78.222	6	13.0370	2.5169
R x T (Error A)	62.157	12	5.1798	
<hr/>				
Variety	615.161	2	307.5805	135.2537**
V x T	80.495	12	6.7079	2.9497**
Error B	63.673	28	2.2741	
V x R				
V x R x T				
Total	901.291	62		

\*\* The value for "F" is significant at the one percent level.

Table 29. Analysis of variance for number of branches per plant in the shade experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	2.894	2	1.4470	
Time of Shading	29.978	5	5.9956	2.1989
R x T (Error A)	27.266	10	2.7266	
<hr/>				
Variety	83.723	2	41.8615	38.6711**
V x T	10.370	10	1.0370	
Error B	25.980	24	1.0825	
V x R				
V x R x T				
Total	180.211	53		

\*\* The value for "F" is significant at the one percent level.

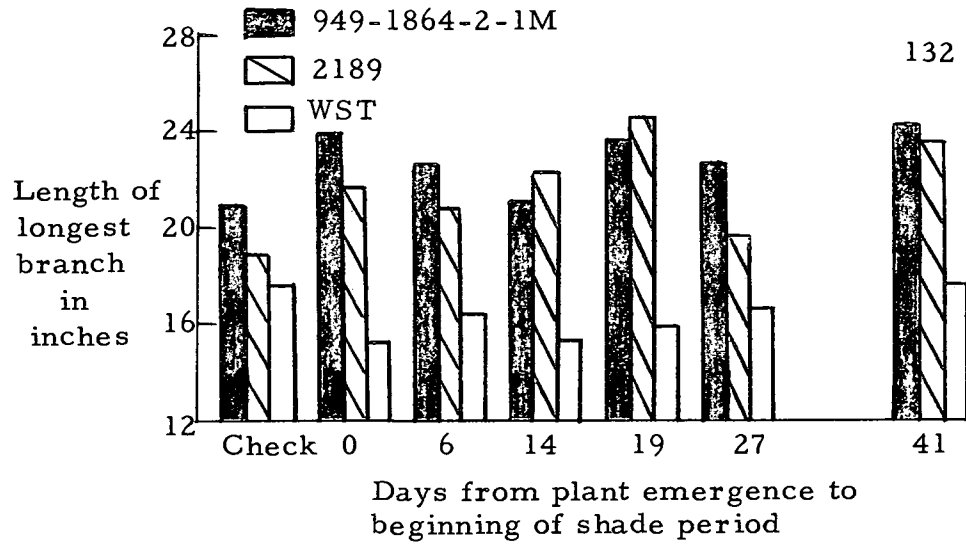


Figure 27. Graphic comparison of the influence of a five-day period of shade on the length of the longest branch.

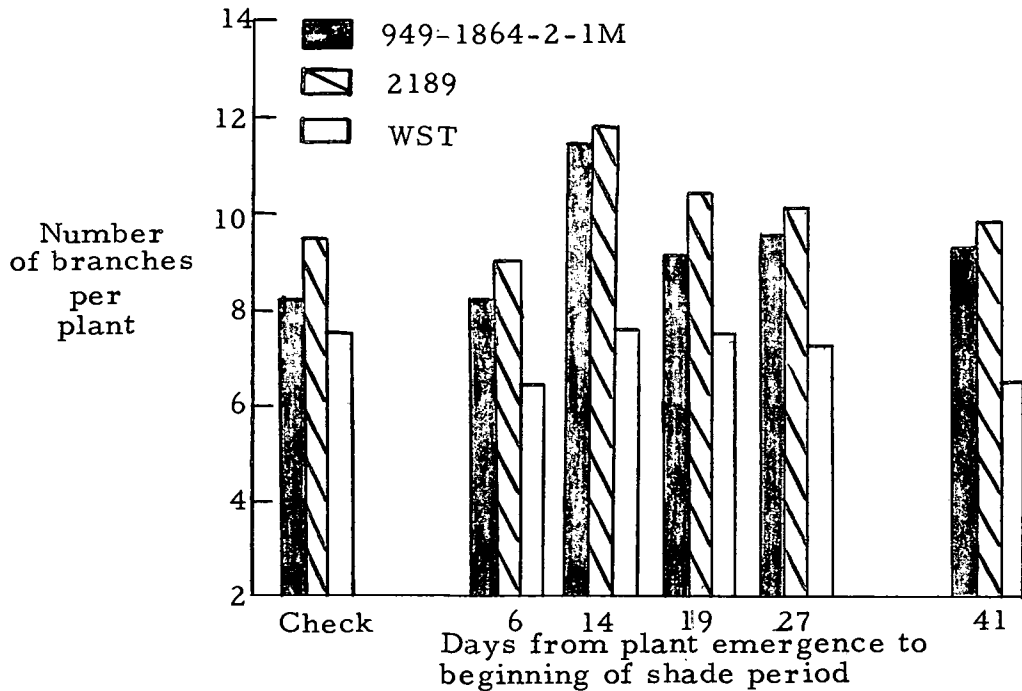


Figure 28. Graphic comparison of the influence of a five-day period of shade on the number of branches.

Table 30. Analysis of variance for pod set in the shade experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	6.1940	2	3.0970	2.2654
Time of Shading	42.3194	7	6.0456	4.4223**
R x T (Error A)	19.1393	14	1.3671	
-----				
Variety	42.8611	2	21.4306	18.7031**
V x T	5.1389	14	0.3671	
Error B	36.6667	32	1.1458	
V x R				
V x R x T				
Total	152.3194	71		

\*\* The value for "F" is significant at the one percent level.

Table 31. Analysis of variance for yield in tons per acre in the shade experiment.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Replication	8.2287	2	4.1144	7.5192**
Time of Shading	17.7448	7	2.5350	4.6328**
R x T (Error A)	7.6605	14	0.5472	
-----				
Variety	12.4831	2	6.2415	9.7459**
V x T	5.5583	14	0.3970	
Error B	20.4938	32	0.6404	
V x R				
V x R x T				
Total	72.1692	71		

\*\* The value for "F" is significant at the one percent level.



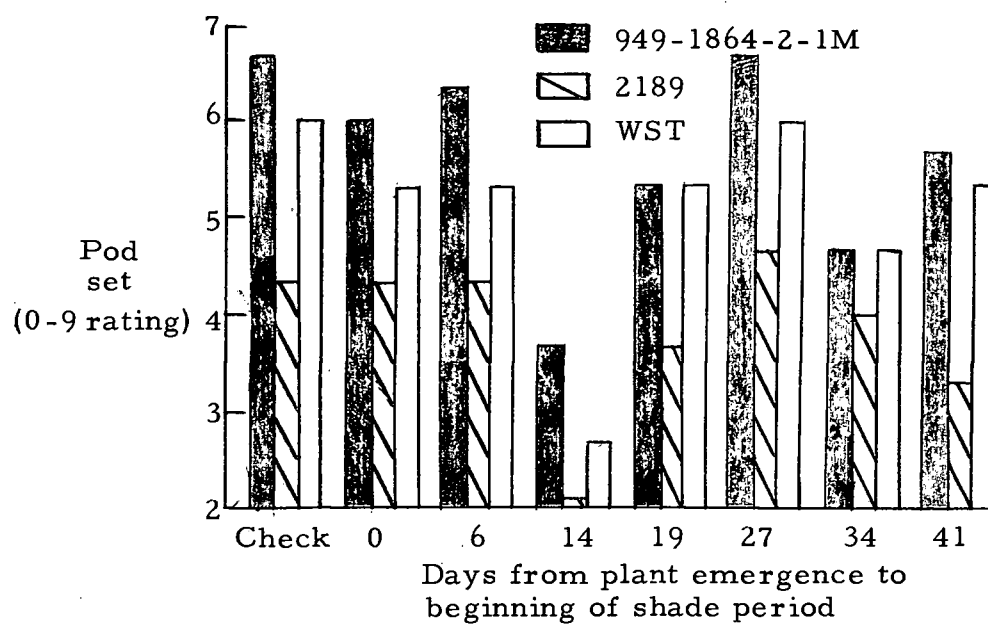


Figure 29. Graphic comparison of the influence of a five-day period of shade on pod set.

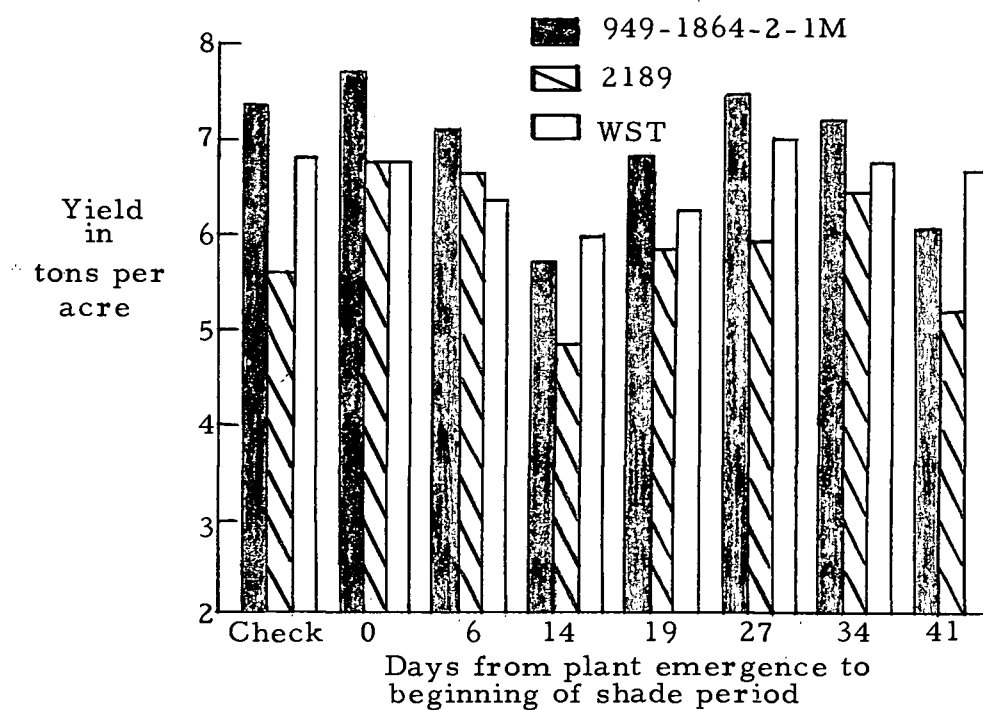


Figure 30. Graphic comparison of the influence of a five-day period of shade on yield.

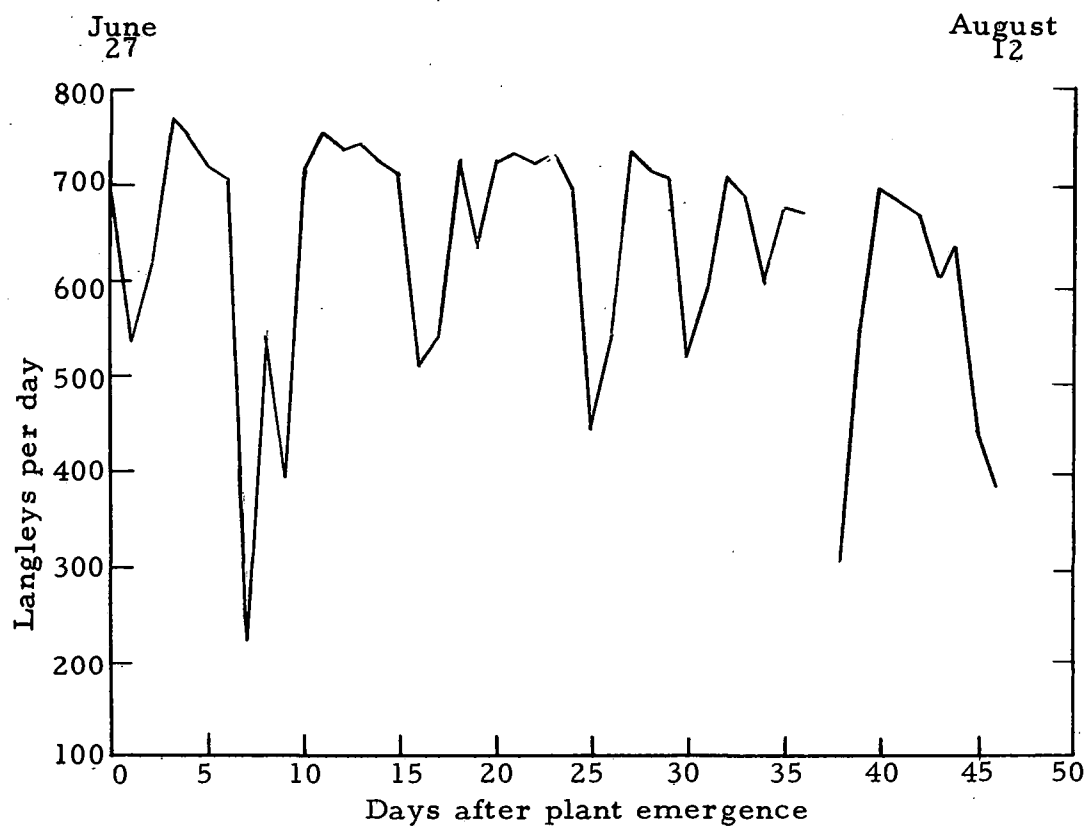


Figure 31. Total daily solar radiation from June 27 to August 12, 1961, as recorded by a pyrliometer in the general area of the shade experiment. Data for the 37th day is missing.

Table 32. Growth habit means (0-9 rating) of parents and of  $F_1$  and  $F_2$  families grown in the field diallel.

Early planting, close spacing									
$F_1$					$F_2$				
$\begin{array}{c} \text{♀} \backslash \text{♂} \\ \text{---} \end{array}$	WST	836-9	2466	PG	$\begin{array}{c} \text{♀} \backslash \text{♂} \\ \text{---} \end{array}$	WST	836-9	2466	PG
WST	<u>8.48</u>	6.65	6.20	8.35	WST	<u>8.48</u>	7.08	5.71	8.66
836-9	5.97	<u>3.93</u>	3.90	4.15	836-9	6.89	<u>3.93</u>	4.12	4.77
2466	6.40	3.68	<u>2.68</u>	5.20	2466	5.71	4.25	<u>2.68</u>	5.32
PG	7.87	3.52	4.28	<u>8.25</u>	PG	8.43	4.90	4.52	<u>8.25</u>
Early planting, wide spacing									
$F_1$					$F_2$				
$\begin{array}{c} \text{♀} \backslash \text{♂} \\ \text{---} \end{array}$	WST	836-9	2466	PG	$\begin{array}{c} \text{♀} \backslash \text{♂} \\ \text{---} \end{array}$	WST	836-9	2466	PG
WST	<u>8.65</u>	5.14	4.82	8.09	WST	<u>8.65</u>	6.61	5.75	8.46
836-9	7.08	<u>4.68</u>	4.22	6.36	836-9	7.26	<u>4.68</u>	4.03	5.17
2466	5.83	3.46	<u>2.55</u>	5.06	2466	5.95	4.44	<u>2.55</u>	6.09
PG	8.29	6.21	5.85	<u>8.53</u>	PG	8.37	4.85	4.59	<u>8.53</u>
Late planting, close spacing									
$F_1$					$F_2$				
$\begin{array}{c} \text{♀} \backslash \text{♂} \\ \text{---} \end{array}$	WST	836-9	2466	PG	$\begin{array}{c} \text{♀} \backslash \text{♂} \\ \text{---} \end{array}$	WST	836-9	2466	PG
WST	7.60	3.38	2.33	6.15	WST	7.60	4.52	4.05	6.94
836-9	<u>3.73</u>	<u>2.35</u>	2.38	2.53	836-9	<u>4.14</u>	<u>2.35</u>	2.61	3.78
2466	3.13	2.35	<u>1.38</u>	3.00	2466	4.24	<u>3.06</u>	<u>1.38</u>	3.44
PG	6.50	2.15	2.22	<u>7.23</u>	PG	6.87	3.77	<u>3.37</u>	<u>7.23</u>
Late planting, wide spacing									
$F_1$					$F_2$				
$\begin{array}{c} \text{♀} \backslash \text{♂} \\ \text{---} \end{array}$	WST	836-9	2466	PG	$\begin{array}{c} \text{♀} \backslash \text{♂} \\ \text{---} \end{array}$	WST	836-9	2466	PG
WST	<u>7.70</u>	3.59	2.83	5.93	WST	<u>7.70</u>	4.98	4.13	6.71
836-9	3.77	<u>2.48</u>	2.70	3.10	836-9	<u>4.66</u>	<u>2.48</u>	2.47	4.02
2466	3.03	2.55	<u>1.25</u>	2.55	2466	4.07	<u>2.60</u>	<u>1.25</u>	3.48
PG	6.18	1.84	1.91	<u>7.16</u>	PG	6.32	4.31	<u>3.25</u>	<u>7.16</u>

Table 33. Analysis of variance for growth habit in the field diallel.

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Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Planting time	392.136	1	392.136	179.0575**
Replication	11.254	3	3.751	1.7128
R x P (Error A)	6.572	3	2.190	
Spacing	5.899	1	5.899	9.4384*
S x P	5.226	1	5.226	8.3616*
Error B	3.750	6	0.625	
S x R	1.513	3	0.504	
S x R x P	2.237	3	0.745	
Genotypes	1,205.462	27	44.646	84.2377**
Parents	463.742	3	154.580	291.6603**
F <sub>1</sub>	346.098	11	31.463	59.3642**
F <sub>2</sub>	341.881	11	31.080	58.6415**
P vs F <sub>1</sub> vs F <sub>2</sub>	53.741	2	26.870	50.6981**
G x Planting Time	44.491	27	1.647	3.1075**
Parents	2.001	3	0.667	1.2585
F <sub>1</sub>	17.556	11	1.596	3.0113**
F <sub>2</sub>	11.273	11	1.024	1.9321*
P vs F <sub>1</sub> vs F <sub>2</sub>	13.661	2	6.830	12.8867**
G x Spacing	21.863	27	0.809	1.5264
Parents	0.647	3	0.215	
F <sub>1</sub>	15.124	11	1.374	2.5924**
F <sub>2</sub>	2.605	11	0.236	
P vs F <sub>1</sub> vs F <sub>2</sub>	3.487	2	1.743	3.2887*
G x P x S	22.487	27	0.832	1.5698
Parents	0.505	3	0.168	
F <sub>1</sub>	24.532	11	2.230	4.2075**
F <sub>2</sub>	2.674	11	0.243	
P vs F <sub>1</sub> vs F <sub>2</sub>	5.224	2		
Error C	170.779	322	0.530	
Total	1,889.919	445		

\* and \*\* The value for "F" is significant at the five and one percent levels, respectively.

Table 34. Plant-height means (in centimeters) of parents and of  $F_1$  and  $F_2$  families grown in the field diallel.

Early planting, close spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>12.00</u>	16.45	18.45	17.06	WST	<u>12.00</u>	16.87	19.22	17.32
836-9	18.11	<u>18.43</u>	18.83	22.00	836-9	15.75	<u>18.43</u>	18.67	22.32
2466	19.83	19.08	<u>17.03</u>	25.20	2466	17.94	19.97	<u>17.03</u>	22.28
PG	17.38	27.49	24.03	<u>17.30</u>	PG	17.12	22.94	24.58	<u>17.30</u>
Early planting, wide spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>11.55</u>	14.87	11.90	16.36	WST	<u>11.55</u>	14.60	16.86	14.99
836-9	14.70	<u>15.68</u>	17.53	20.49	836-9	14.53	<u>15.68</u>	14.56	20.93
2466	18.60	13.89	<u>12.23</u>	19.32	2466	15.04	14.98	<u>12.23</u>	19.20
PG	14.45	21.69	23.49	<u>14.50</u>	PG	14.43	20.47	22.66	<u>14.50</u>
Late planting, close spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>24.38</u>	44.05	34.00	33.45	WST	<u>24.38</u>	34.30	35.17	32.82
836-9	43.05	<u>38.11</u>	32.38	42.40	836-9	36.00	<u>38.11</u>	36.79	42.86
2466	35.55	32.78	<u>42.48</u>	44.85	2466	34.90	37.16	<u>42.48</u>	42.00
PG	37.88	53.88	47.90	<u>30.80</u>	PG	31.59	41.63	40.86	<u>30.80</u>
Late planting, wide spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>23.03</u>	31.46	25.38	32.70	WST	<u>23.03</u>	28.76	26.66	29.75
836-9	35.14	<u>32.73</u>	26.06	39.27	836-9	29.04	<u>32.73</u>	29.31	34.48
2466	24.03	25.48	<u>27.45</u>	39.68	2466	28.02	29.52	<u>27.45</u>	33.06
PG	31.08	46.53	40.36	<u>24.66</u>	PG	28.26	35.27	34.43	<u>24.66</u>

Table 35. Analysis of variance for plant height in the field diallel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Planting Time	31,591.630	1	31,591.630	285.3805**
Replication	1,905.760	3	635.253	5.7385
R x P (Error A)	332.100	3	110.700	
Spacing	2,386.570	1	2,386.570	66.5227**
S x P	570.010	1	570.010	15.8908**
Error B	215.260	6	35.876	
S x R	89.680	3	29.893	3.1135*
S x R x P	125.580	3	41.860	4.3600**
Genotypes	7,052.110	27	261.189	27.0354**
Parents	649.080	3	216.360	22.3952**
F <sub>1</sub>	3,676.200	11	334.200	34.5927**
F <sub>2</sub>	1,578.760	11	143.523	14.8559**
P vs F <sub>1</sub> vs F <sub>2</sub>	1,148.070	2	574.035	
G x Planting Time	1,912.370	27	70.828	7.3313**
Parents	242.747	3	80.915	8.3754**
F <sub>1</sub>	1,383.370	11	125.760	13.0172**
F <sub>2</sub>	85.270	11	7.751	0.8023
P vs F <sub>1</sub> vs F <sub>2</sub>	200.983	2	100.491	
G x Spacing	429.150	27	15.894	1.6452*
Parents	171.657	3	57.219	5.9227**
F <sub>1</sub>	200.010	11	18.182	1.8820*
F <sub>2</sub>	57.210	11	5.200	0.5382
P vs F <sub>1</sub> vs F <sub>2</sub>	0.273	2	0.136	
G x P x S	279.440	27	10.349	
Parents	129.557	3	43.185	
F <sub>1</sub>	484.780	11	44.070	
F <sub>2</sub>	234.940	11	21.358	
P vs F <sub>1</sub> vs F <sub>2</sub>	- 569.837	2		
Error C	3,110.950	322	9.661	
	49,785.350	445		

\* and \*\* The value for "F" is significant at the five and one percent levels, respectively.

Table 36. Plant-length means (in centimeters) of parents and of  $F_1$  and  $F_2$  families grown in the field diallel.

Early planting, close spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>33.70</u>	44.28	50.80	40.50	WST	<u>33.70</u>	39.28	38.90	34.37
836-9	51.17	<u>30.55</u>	34.70	50.93	836-9	40.25	<u>30.55</u>	33.37	49.96
2466	48.03	34.00	25.98	42.70	2466	39.47	33.10	<u>25.98</u>	40.82
PG	45.06	52.41	43.76	<u>31.63</u>	PG	39.27	49.37	44.73	<u>31.63</u>
Early planting, wide spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>32.18</u>	53.39	49.63	44.53	WST	<u>32.18</u>	38.80	39.11	37.91
836-9	53.75	<u>32.33</u>	35.73	44.75	836-9	39.22	<u>32.33</u>	30.89	49.20
2466	48.87	29.24	<u>26.20</u>	41.22	2466	38.63	32.12	<u>26.20</u>	42.29
PG	41.94	49.41	48.84	<u>34.60</u>	PG	38.24	51.33	42.98	<u>34.60</u>
Late planting, close spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>48.10</u>	65.68	72.95	59.93	WST	<u>48.10</u>	51.85	49.51	53.80
836-9	64.68	<u>51.04</u>	51.35	67.03	836-9	53.19	<u>51.38</u>	48.87	59.30
2466	68.70	47.45	<u>47.88</u>	59.28	2466	50.37	49.86	<u>47.88</u>	56.94
PG	60.65	68.13	63.93	<u>47.25</u>	PG	53.75	57.43	54.37	<u>47.25</u>
Late planting, wide spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>49.28</u>	65.51	70.27	63.30	WST	<u>49.28</u>	53.06	51.60	54.14
836-9	68.73	<u>51.23</u>	49.77	68.38	836-9	52.67	<u>51.23</u>	49.44	56.51
2466	65.35	43.30	<u>44.40</u>	61.78	2466	52.37	48.76	<u>44.40</u>	55.12
PG	56.86	72.82	68.02	<u>46.36</u>	PG	54.68	57.83	57.16	<u>46.36</u>

Table 37. Analysis of variance for plant length in the field diallel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Planting Time	29,411.800	1	29,411.800	101.0021**
Replication	1,310.900	3	436.967	1.5006
R x P (Error A)	873.600	3	291.200	
Spacings	45.300	1	45.300	
S x P	21.800	1	21.800	
Error B	172.300	6	25.628	
S x R	93.500	3	31.167	
S x R x P	78.800	3	26.267	
Genotypes	21,249.100	27	787.004	31.2340**
Parents	265.380	3	72.631	2.8825*
F <sub>1</sub>	7,767.240	11	706.113	28.0237**
F <sub>2</sub>	3,133.940	11	284.904	11.3071**
P vs F <sub>1</sub> vs F <sub>2</sub>	10,082.540	2	5,041.270	200.0742**
G x Planting Time	1,807.200	27	66.933	26.5639**
Parents	114.780	3	38.260	
F <sub>1</sub>	91.910	11	8.355	
F <sub>2</sub>	475.300	11	43.209	1.7148
P vs F <sub>1</sub> vs F <sub>2</sub>	1,125.210	2	562.600	22.3281**
G x Spacing	1,013.800	27	37.548	1.4902
Parents	18.850	3	6.283	
F <sub>1</sub>	896.200	11	81.473	3.2334*
F <sub>2</sub>	51.790	11	4.708	
P vs F <sub>1</sub> vs F <sub>2</sub>	46.960	2	23.480	
G x P x S	459.300	27	17.011	
Parents	38.400	3	12.800	
F <sub>1</sub>	344.770	11	31.343	
F <sub>2</sub>	76.250	11	6.932	
P vs F <sub>1</sub> vs F <sub>2</sub>	0.120	2		
Error C	8,113.300	322	25.197	
Total	64,478.400	445		

\* and \*\* The value for "F" is significant at the five and one percent levels, respectively.



Table 38. Mean length of central stem internodes (in centimeters) for parents and for  $F_1$  and  $F_2$  families grown in the field diallel.

Early planting, close spacing									
$F_1$					$F_2$				
$\begin{array}{c} \text{♀} \diagup \text{♂} \\ \hline \end{array}$	WST	836-9	2466	PG	$\begin{array}{c} \text{♀} \diagup \text{♂} \\ \hline \end{array}$	WST	836-9	2466	PG
WST	<u>3.86</u>	4.45	5.52	4.03	WST	<u>3.86</u>	4.61	5.09	4.32
836-9	5.54	<u>4.60</u>	4.21	5.99	836-9	4.79	<u>4.60</u>	4.44	5.94
2466	4.17	3.93	<u>3.82</u>	4.80	2466	4.45	4.41	<u>3.82</u>	5.02
PG	4.60	5.69	5.18	<u>4.02</u>	PG	4.51	5.57	5.66	<u>4.02</u>
Early planting, wide spacing									
$F_1$					$F_2$				
$\begin{array}{c} \text{♀} \diagup \text{♂} \\ \hline \end{array}$	WST	836-9	2466	PG	$\begin{array}{c} \text{♀} \diagup \text{♂} \\ \hline \end{array}$	WST	836-9	2466	PG
WST	<u>2.78</u>	2.87	3.03	3.61	WST	<u>2.78</u>	3.39	3.48	3.38
836-9	3.96	<u>3.20</u>	3.85	4.26	836-9	3.47	<u>3.20</u>	3.06	4.84
2466	3.23	2.75	<u>2.40</u>	3.25	2466	3.36	2.84	<u>2.40</u>	3.69
PG	3.50	4.51	4.36	<u>2.78</u>	PG	3.33	4.83	4.27	<u>2.78</u>
Late planting, close spacing									
$F_1$					$F_2$				
$\begin{array}{c} \text{♀} \diagup \text{♂} \\ \hline \end{array}$	WST	836-9	2466	PG	$\begin{array}{c} \text{♀} \diagup \text{♂} \\ \hline \end{array}$	WST	836-9	2466	PG
WST	<u>5.54</u>	7.23	6.04	5.69	WST	<u>5.54</u>	6.41	6.41	5.65
836-9	7.08	<u>6.48</u>	6.40	6.90	836-9	6.50	<u>6.48</u>	6.71	6.69
2466	5.99	6.10	<u>8.85</u>	6.36	2466	6.22	6.66	<u>8.85</u>	6.96
PG	6.26	7.71	6.71	<u>4.50</u>	PG	5.63	6.38	6.66	<u>4.50</u>
Late planting, wide spacing									
$F_1$					$F_2$				
$\begin{array}{c} \text{♀} \diagup \text{♂} \\ \hline \end{array}$	WST	836-9	2466	PG	$\begin{array}{c} \text{♀} \diagup \text{♂} \\ \hline \end{array}$	WST	836-9	2466	PG
WST	<u>5.43</u>	4.87	4.43	4.64	WST	<u>5.43</u>	5.09	4.35	4.19
836-9	5.24	<u>5.15</u>	4.42	5.46	836-9	4.65	<u>5.15</u>	4.98	6.08
2466	5.05	4.62	<u>5.41</u>	4.66	2466	4.66	4.92	<u>5.41</u>	4.86
PG	4.53	5.69	4.57	<u>3.18</u>	PG	4.47	4.86	5.17	<u>3.18</u>

Table 39. Means of number of central stem internodes for parents and for  $F_1$  and  $F_2$  families grown in the field diallel,

Early planting, close spacing								
$F_1$					$F_2$			
$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466 PG
WST	<u>4.15</u>	4.09	3.30	4.22	WST	<u>4.15</u>	4.11	3.56 4.46
836-9	4.26	<u>4.05</u>	3.22	4.43	836-9	4.15	<u>4.05</u>	3.33 5.16
2466	3.33	3.12	<u>3.03</u>	3.32	2466	3.45	3.45	<u>3.03</u> 3.69
PG	4.50	4.32	3.39	<u>4.60</u>	PG	4.76	5.13	3.91 <u>4.60</u>
Early planting, wide spacing								
$F_1$					$F_2$			
$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466 PG
WST	<u>4.15</u>	4.07	3.36	4.21	WST	<u>4.15</u>	3.99	3.51 4.55
836-9	4.39	<u>4.08</u>	3.54	4.21	836-9	4.16	<u>4.08</u>	3.45 5.20
2466	3.43	3.10	<u>3.00</u>	3.26	2466	3.46	3.41	<u>3.00</u> 3.71
PG	4.59	4.32	3.68	<u>4.75</u>	PG	4.64	5.09	3.63 <u>4.75</u>
Late planting, close spacing								
$F_1$					$F_2$			
$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466 PG
WST	<u>4.98</u>	4.78	3.74	4.92	WST	<u>4.98</u>	4.95	4.12 5.58
836-9	5.00	<u>4.98</u>	3.88	5.37	836-9	5.04	<u>4.98</u>	4.22 5.42
2466	3.93	3.70	<u>3.73</u>	3.95	2466	4.27	4.22	<u>3.73</u> 4.49
PG	5.49	5.30	4.01	<u>5.75</u>	PG	5.60	5.43	4.57 <u>5.75</u>
Late planting, wide spacing								
$F_1$					$F_2$			
$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466 PG
WST	<u>5.23</u>	4.78	3.80	5.18	WST	<u>5.23</u>	5.14	4.28 5.51
836-9	5.27	<u>5.00</u>	3.98	5.28	836-9	4.88	<u>5.00</u>	4.15 5.45
2466	3.65	3.64	<u>3.64</u>	4.06	2466	4.27	4.18	<u>3.64</u> 4.36
PG	5.17	5.39	4.18	<u>5.77</u>	PG	5.69	5.55	4.33 <u>5.77</u>

Table 40. Analysis of variance for number of central stem internodes in the field diallel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Planting Time	74.924	1	74.924	226.3565**
Replication	1.761	3	0.587	
R x P (Error A)	0.995	3	0.331	
Spacing	0.041	1	0.041	
S x P	0.001	1	0.001	
Error B	1.029	6	0.171	
S x R	0.167	3	0.055	
S x R x P	0.862	3	0.287	
Genotypes	168.744	27	6.249	31.8827**
Parents	29.093	3	9.697	49.3827**
F <sub>1</sub>	58.553	11	5.323	27.1581**
F <sub>2</sub>	66.304	11	6.027	30.7500**
P vs F <sub>1</sub> vs F <sub>2</sub>	14.794	2	7.397	37.7400**
G x Planting Time	8.955	27	0.331	1.6888
Parents	0.260	3	0.086	
F <sub>1</sub>	5.862	11	0.532	2.7143**
F <sub>2</sub>	2.253	11	0.204	
P vs F <sub>1</sub> vs F <sub>2</sub>	0.580	2	0.290	
G x Spacing	5.669	27	0.209	
Parents	0.046	3	0.015	
F <sub>1</sub>	5.153	11	0.468	2.3878**
F <sub>2</sub>	0.315	11	0.028	
P vs F <sub>1</sub> vs F <sub>2</sub>	0.155	2	0.077	
G x S x P	4.213	27	0.156	
Parents	0.066	3	0.022	
F <sub>1</sub>	3.831	11	0.348	
F <sub>2</sub>	0.316	11	0.028	
P vs F <sub>1</sub> vs F <sub>2</sub>	0.000	2	0.000	
Error C	63.113	322	0.196	
Total	329.445	445		

\*\* The value for "F" is significant at the one percent level.

Table 41. Means of number of branches per plant for parents and for  $F_1$  and  $F_2$  families grown in the field diallel.

Early planting, close spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG
WST	<u>3.33</u>	5.18	4.65	4.15	WST	<u>3.33</u>	4.40	4.32	3.93
836-9	5.70	<u>3.75</u>	4.00	4.90	836-9	5.02	<u>3.75</u>	4.32	6.33
2466	4.23	4.23	<u>3.65</u>	4.85	2466	4.32	3.92	<u>3.65</u>	4.77
PG	4.89	6.69	4.98	<u>5.68</u>	PG	5.02	7.57	5.17	<u>5.68</u>
Early planting, wide spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG
WST	<u>6.00</u>	8.99	8.69	7.89	WST	<u>6.00</u>	7.00	6.70	8.07
836-9	8.08	<u>6.25</u>	7.35	8.13	836-9	7.31	<u>6.25</u>	6.22	10.39
2466	7.13	5.94	<u>5.50</u>	7.07	2466	6.94	6.35	<u>5.50</u>	7.61
PG	7.28	10.58	8.34	<u>9.08</u>	PG	8.01	11.65	8.32	<u>9.08</u>
Late planting, close spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG
WST	<u>3.93</u>	7.75	7.40	6.98	WST	<u>3.93</u>	6.21	6.42	6.55
836-9	6.70	<u>7.68</u>	8.18	7.73	836-9	6.58	<u>7.68</u>	7.69	7.39
2466	8.53	7.33	<u>7.03</u>	7.18	2466	6.61	7.09	<u>7.03</u>	7.32
PG	6.70	8.50	8.03	<u>7.85</u>	PG	6.50	7.47	7.48	<u>7.85</u>
Late planting, wide spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}} \rightarrow$	WST	836-9	2466	PG
WST	<u>7.85</u>	12.44	11.49	10.85	WST	<u>7.85</u>	10.21	9.72	11.01
836-9	12.91	<u>12.53</u>	10.51	14.83	836-9	10.22	<u>12.53</u>	10.50	13.39
2466	11.03	9.69	<u>9.15</u>	11.58	2466	10.37	9.87	<u>9.15</u>	11.97
PG	9.63	14.75	11.67	<u>13.07</u>	PG	11.73	13.35	12.14	<u>13.07</u>

Table 42. Analysis of variance for number of branches per plant in the field diallel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio
Planting Time	1,060.500	1	1,060.500	188.3324**
Replication	30.696	3	10.232	
R x P (Error B)	16.895	3	5.631	
Spacing	1,469.872	1	1,469.872	2,405.6825**
S x P	37.212	1	37.212	60.9034**
Error B	3.666	6	0.611	
S x R	1.757	3	0.585	
S x R x P	1.909	3	0.636	
Genotypes	452.524	27	16.760	16.6435**
Parents	118.170	3	39.390	39.1162**
F <sub>1</sub>	104.910	11	9.537	9.4707**
F <sub>2</sub>	186.397	11	16.945	16.8272**
P vs F <sub>1</sub> vs F <sub>2</sub>	43.047	2	21.523	21.3734**
G x Planting	94.409	27	3.496	3.4717**
Parents	30.415	3	10.138	10.0675**
F <sub>1</sub>	22.632	11	2.057	2.0427*
F <sub>2</sub>	27.065	11	2.460	2.4429**
P vs F <sub>1</sub> vs F <sub>2</sub>	14.297	2	7.148	7.0983**
G x Spacing	101.013	27	3.741	3.7150**
Parents	11.271	3	3.757	3.7309*
F <sub>1</sub>	53.349	11	4.849	4.8153**
F <sub>2</sub>	34.353	11	3.123	3.1013**
P vs F <sub>1</sub> vs F <sub>2</sub>	2.040	2	1.020	
G x P x S	28.590	27	1.058	
Parents	10.455	3	3.485	3.4608*
F <sub>1</sub>	30.753	11	2.795	2.7756*
F <sub>2</sub>	24.597	11	2.236	2.2205*
P vs F <sub>1</sub> vs F <sub>2</sub>	- 37.215	2	- 18.607	
Error C	324.154	322	1.007	
Total	3,619.531	445		

\* and \*\* The value for "F" is significant at the five and one percent levels, respectively.

Table 43. Pod-placement means (0-9 rating) for parent and for  $F_1$  and  $F_2$  families grown in the field diallel.

Late planting, close spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>7.69</u>	6.74	5.36	6.89	WST	<u>7.69</u>	6.14	6.00	7.30
836-9	6.91	<u>6.85</u>	4.91	7.10	836-9	6.53	<u>6.85</u>	5.76	7.04
2466	6.16	5.28	<u>4.36</u>	6.68	2466	6.04	5.70	<u>4.36</u>	6.33
PG	7.00	7.40	6.18	<u>7.33</u>	PG	7.07	7.02	6.40	<u>7.33</u>

Late planting, wide spacing									
$F_1$					$F_2$				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>7.14</u>	5.96	4.05	6.60	WST	<u>7.14</u>	6.28	4.91	6.72
836-9	6.64	<u>5.78</u>	4.13	6.53	836-9	6.03	<u>5.78</u>	4.55	6.38
2466	4.09	4.06	<u>2.56</u>	5.33	2466	5.05	4.42	<u>2.56</u>	5.55
PG	5.96	6.55	5.25	<u>6.44</u>	PG	6.39	6.61	5.11	<u>6.44</u>

Table 44. Means of several characters observed in the  $F_1$  and parents grown in the greenhouse diallel.

Growth habit (0-9 rating)					Plant height in centimeters at 30 days				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	6.00	3.00	3.50	5.75	WST	<u>41.80</u>	64.65	51.55	41.15
836-9	<u>3.50</u>	<u>3.75</u>	2.68	2.50	836-9	67.64	<u>61.75</u>	53.07	80.75
2466	3.00	3.00	<u>2.75</u>	2.50	2466	73.35	53.75	<u>63.76</u>	73.95
PG	5.25	2.75	2.25	<u>4.75</u>	PG	44.00	82.15	82.75	<u>55.87</u>

Number of branches					Plant length in centimeters				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	<u>3.47</u>	4.30	2.65	3.00	WST	<u>47.53</u>	73.90	62.20	44.65
836-9	4.10	<u>4.90</u>	3.13	5.65	836-9	78.30	<u>66.70</u>	61.27	91.25
2466	2.85	3.35	<u>3.45</u>	3.65	2466	83.90	58.60	<u>67.40</u>	88.45
PG	3.10	5.50	4.15	<u>6.58</u>	PG	47.20	90.45	94.45	<u>58.15</u>

Number of internodes					Mean internode length in centimeters				
$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG	$\frac{\text{♀}}{\text{♂}}$	WST	836-9	2466	PG
WST	3.95	3.96	3.12	3.92	WST	<u>8.85</u>	15.13	16.12	9.51
836-9	<u>4.04</u>	<u>4.00</u>	3.00	4.16	836-9	15.77	<u>14.63</u>	16.85	17.54
2466	3.24	3.04	<u>3.00</u>	3.24	2466	20.53	15.40	<u>18.78</u>	21.05
PG	4.44	4.28	3.36	<u>4.67</u>	PG	8.85	17.13	21.76	<u>10.16</u>

Table 45. Chi-square tests of association between pod color and growth habit in F<sub>2</sub> plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Growth habit (0-9 rating)							Total plants	Degrees of freedom	Chi-square	P value
		0-3	4	5	6	7	8	9				
WST x PG	Wax	0	2	9	19	17	5	4	56	6	21.090	<.01
	Green	8	17	21	31	40	53	13	183			
836-9 x PG		0-2	3	4	5	6	7	8-9				
	Wax	9	18	6	7	8	5	3	56	6	5.958	.50-.30
	Green	38	38	37	23	20	19	6	181			
2466 x PG		0-1	2	3	4	5	6	7-9				
	Wax	1	11	17	7	13	2	4	55	6	18.219	<.01
	Green	14	51	46	36	16	9	8	180			

Table 46. Chi-square tests of association between pod color and the number of central stem internodes in F<sub>2</sub> plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Number of internodes					Total plants	Degrees of freedom	Chi-square	P value
		3	4	5	6	7-8				
WST x PG	Wax	0	3	29	18	7	57	3	2.547	.50-.30
	Green	0	4	82	67	30	183			
836-9 x PG		3	4	5	6	7-8				
	Wax	0	5	21	23	7	56	3	8.992	.05-.02
	Green	0	6	92	77	8	183			
2466 x PG		3	4	5	6-7					
	Wax	7	22	13	12		54	3	5.369	.20-.10
	Green	19	102	25	31		177			



Table 47. Chi-square tests of association between pod color and the length of the second internode in  $F_2$  plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Length of second internode in centimeters			Total plants	Degrees of freedom	Chi-square	P value
		1	2	3-				
WST x PG	Wax	36	20	1	57	2	14.094	<.01
	Green	64	106	11	181			
836-9 x PG	Wax	43	15	0	58	2	22.983	<.01
	Green	71	97	14	182			
2466 x PG	Wax	33	21	0	54	2	20.272	<.01
	Green	53	104	21	178			

Table 48. Chi-square tests of association between pod color and the length of the third internode in  $F_2$  plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Length of third internode in centimeters					Total plants	Degrees of freedom	Chi-square	P value
		1	2	3	4	5-				
WST x PG	Wax	23	25	6	2	1	57	4	29.142	<.01
	Green	18	107	43	7	6	181			
836-9 x PG	Wax	16	26	9	3	2	56	4	17.790	<.01
	Green	16	82	48	27	10	183			
2466 x PG	Wax	10	27	9	2	7	55	4	24.598	<.01
	Green	8	54	54	35	28	179			

Table 49. Chi-square tests of association between pod color and the mean length of central stem internodes in  $F_2$  plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Mean internode length in centimeters						Total plants	Degrees of freedom	Chi-square	P value
		-2	3	4	5	6	7-				
WST x PG	Wax	6	14	24	8	1	0	53	5	22.621	<.01
	Green	3	30	61	50	24	7	175			
836-9 x PG	Wax	4	12	13	11	7	5	52	5	6.625	.30-.20
	Green	5	23	44	48	31	25	176			
2466 x PG	Wax	7	14	6	16	8	4	55	5	14.265	.02-.01
	Green	12	31	37	38	21	40	179			

Table 50. Chi-square tests of association between pod color and plant length in  $F_2$  plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Plant length in centimeters						Total plants	Degrees of freedom	Chi-square	P value
		41-40	51-50	61-60	71-70	81-80	91-				
WST x PG	Wax	10	13	23	11	0	0	57	5	19.038	<.01
	Green	5	48	73	43	9	2	180			
836-9 x PG	Wax	5	14	25	7	4	0	55	5	13.049	.05-.02
	Green	7	26	70	57	18	5	183			
2466 x PG	Wax	10	13	17	12	1	2	55	5	12.662	.05-.02
	Green	11	34	55	46	23	9	178			

Table 51. Chi-square tests of association between pod color and height of  $F_2$  plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Plant height in centimeters				Total plants	Degrees of freedom	Chi-square	P value
		11-20	21-30	31-40	41-				
WST x PG	Wax	13	32	12	1	58	3	13.764	<.01
	Green	20	74	73	15	182			
836-9 x PG	Wax	6	15	26	9	56	3	5.734	.20-.10
	Green	7	44	84	48	183			
2466 x PG	Wax	7	24	16	8	55	3	5.936	.20-.10
	Green	12	59	68	43	182			

Table 52. Chi-square tests of association between pod color and number of branches per plant in  $F_2$  plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Number of branches per plant					Total plants	Degrees of freedom	Chi-square	P value
		-8	9-12	13-16	17-20	21-				
WST x PG	Wax	10	15	23	7	2	57	4	11.467	.05-.02
	Green	54	70	40	14	3	181			
836-9 x PG	Wax	5	15	22	9	5	56	4	5.444	.30-.20
	Green	16	76	51	30	9	182			
2466 x PG	Wax	6	27	15	9	2	59	4	7.203	.20-.10
	Green	40	63	53	15	4	175			

Table 53. Chi-square tests of association between pod color and pod placement  
in F<sub>2</sub> plants from the wide-spaced, late planting of the field diallel.

Cross	Pod color	Pod placement (0-9 rating)					Total plants	Degrees of freedom	Chi- square	P value
		0-4	5	6	7	8				
WST x PG	Wax	9	7	14	21	5	56	4	25.960	<.01
	Green	2	19	34	81	41	177			
836-9 x PG	Wax	3	9	14	21	8	55	4	7.481	.20-.10
	Green	8	10	48	88	20	174			
2466 x PG		0-3	4	5	6	7	8	5	2.304	.80-.70
	Wax	9	9	11	10	14	2			
	Green	22	22	43	43	38	8			



Figure 32. Field layout of the split, split plot design of parents,  $F_1$ , and  $F_2$  prior to the second planting.



Figure 33. The four parental varieties used in diallel crossing. These plants were grown in the field at wide spacing in the late planting. Most leaves have been removed.

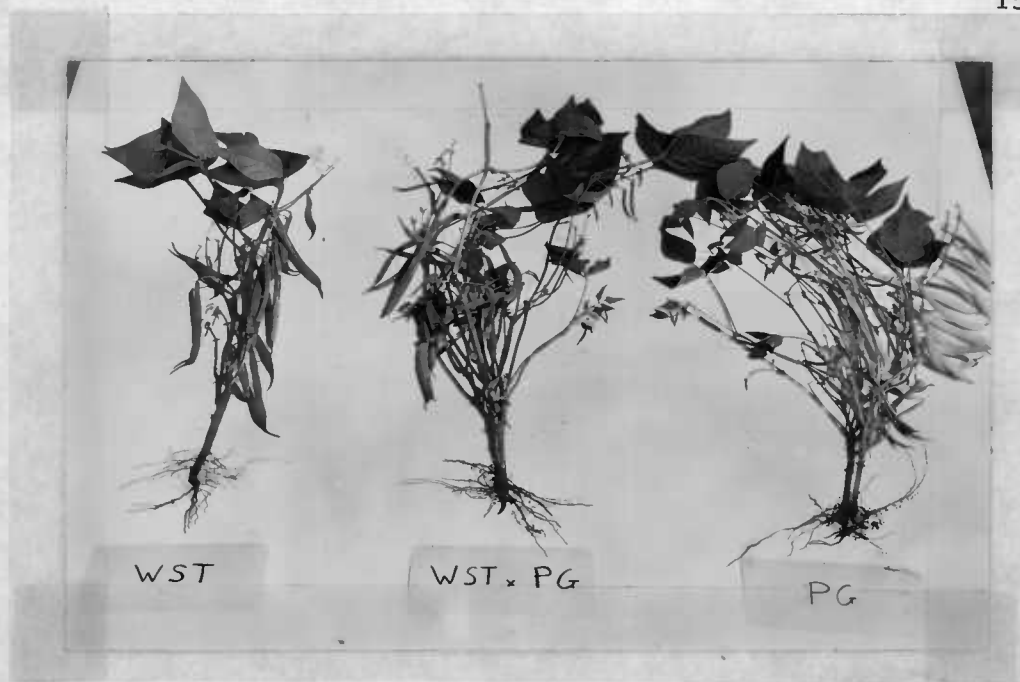


Figure 34. WST, PG, and their  $F_1$  hybrid grown in the field at wide spacing in the late planting. Most leaves have been removed.

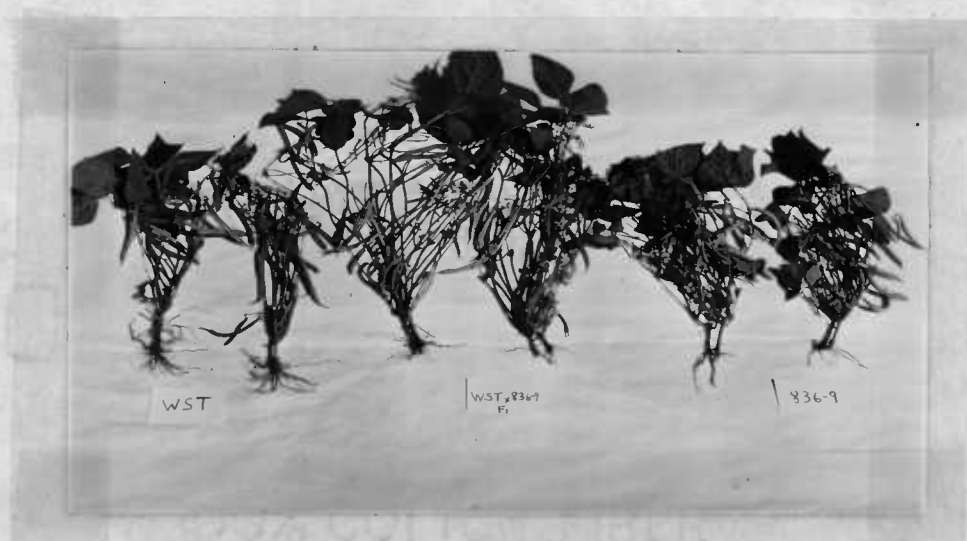


Figure 35. WST, 836-9, and their  $F_1$  hybrid grown in the field at wide spacing in the late planting. Most leaves have been removed.

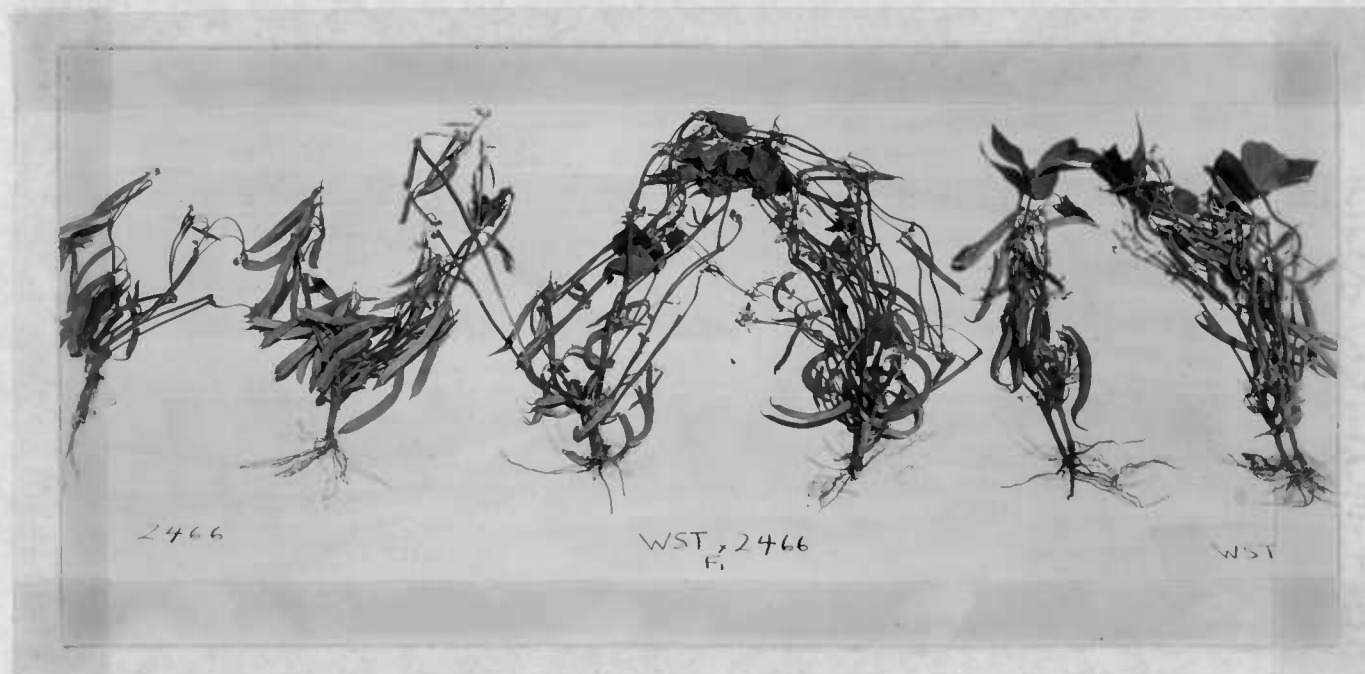


Figure 36. WST, 2466, and their  $F_1$  hybrid grown in the field at wide spacing in the late planting. Most leaves have been removed.



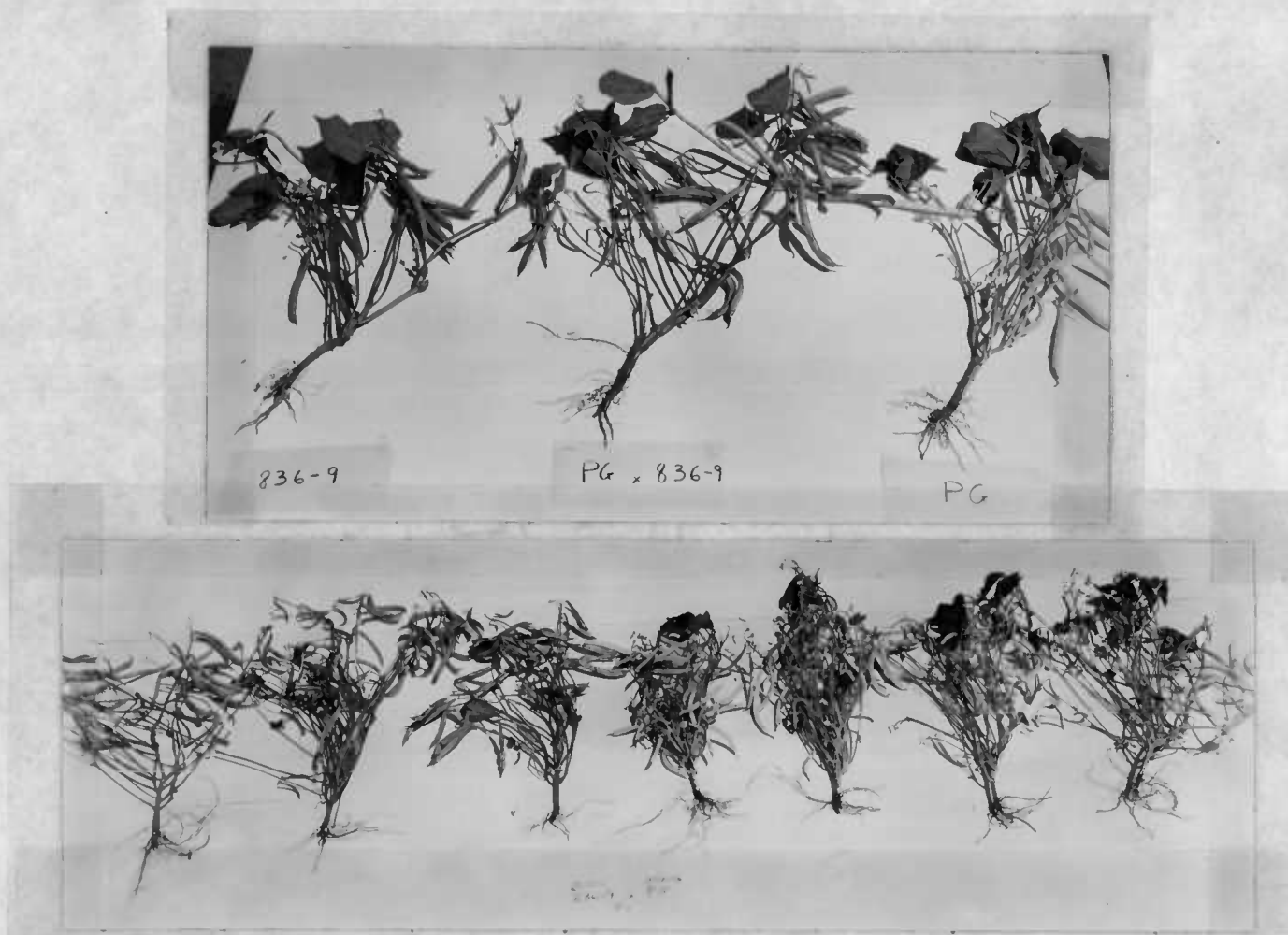


Figure 37. 836-9, PG, and their  $F_1$  (Top) and  $F_2$  (Bottom) hybrids grown in the field at wide spacing in the late planting. Most leaves have been removed. In the  $F_2$  the four plants to the right are "wax" segregates.



Figure 38. PG, 2466, and their  $F_1$  hybrid grown in the field at wide spacing in the late planting. Most leaves have been removed.



Figure 39. 836-9, 2466, and their  $F_1$  hybrid grown in the field at wide spacing and in the late planting. Most leaves have been removed.