FACTORS AFFECTING GROWTH AND FRUITING OF

PHASEOLUS VULGARIS L.

by

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Abstract

Experiments were conducted in controlled-environment cabinets to show the effect of temperature and light intensity on the growth and fruiting of snap beans. Leaf weights varied inversely with the temperature, but stem weights and numbers of nodes were not greatly affected by day temperature in the range of 75° to 95°F. Blossoming and pod set were similar at day temperatures of 75° and 85°F but were reduced at 95°F. When day temperature was 95°F, a 60°F night temperature resulted in increased blossoming and pod set compared to 80°F. When pods were harvested at marketable maturity, blossoming in bush beans was cyclic. Plants grown at a light intensity of 1900 foot-candles had a lower fresh and dry weight of leaves, stems, and pods, and fewer blossoms and pods set than plants grown at 2700 and 4000 foot-candles.

Field experiments showed that planting dates after May 29 reduced the yield of pods in pole beans. Nitrogen level and row direction did not affect yield of pods in pole beans. Number of pods per plant in pole beans increased directly with the row spacing. Chemical sprays at blossoming caused no increase in yield of pods in pole beans, and only a slight increase in the yield of pods in bush beans. Differences in yields of pods between varieties of bush beans were due differences in the number of pods per plant.

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INTRODUCTION

Yield in beans is largely dependent on the set of pods and low set of pods is closely associated with blossom drop. Investigators have frequently attributed blossom drop in beans to high temperatures, low relative humidity and low available soil moisture (Davis, 1945; Lambeth, 1950; Williams, 1962). Other causal factors mentioned are size of plant (Cordner, 1933), light intensity (Inoue and Suzuki, 1956), soil fertility (Wolf, 1942; Lambeth, 1950), and insects (Baker, et al., 1946; Fisher, et al., 1946). It has been reported that blossom drop could be reduced by the application of growth regulators (Murneek, et al., 1944; Fisher, et al., 1946) and irrigation (Rahn, 1955; Williams, 1962) during the blossoming periods.

Snap beans, *Phaseolus vulgaris* L., are distinctly divided into two groups, pole and bush beans. Pole beans blossom along the stem, which continues to grow indefinitely, its ultimate length depending on environmental conditions. In bush beans the inflorescence is at the tip of the plant, and blossoming is terminal (Wade, 1937). Most varieties of the species *Phaseolus vulgaris* L. are day neutral (Allard and Zaumeyer, 1944). Since pollination in the bean occurs before the blossom opens (Inoue and Shibuya, 1954), beans are a highly self pollinated crop and considered cleistogamous.

The objectives of this study were to investigate in controlled-environment cabinets, the effect of temperature and light intensity on the growth and fruiting response of bush beans and in field experiments to investigate the effect of planting date, nitrogen fertility, row spacing, row direction and chemical sprays on the fruiting response of bush and pole beans.

LITERATURE REVIEW

In field experiments with white pea beans, Davis (1945) studied the effect of maximum temperature, minimum relative humidity, soil moisture, leaf area and fertilizer on the set of pods. Maximum temperature influenced the set of pods more than any other factor studied. Minimum relative humidity and soil moisture exerted only a minor influence on the set of pods. Leaf area and fertilizer levels did not influence the set of pods.

A significant relation between percent pod set and the mean daily temperature was found for snap beans by Lambeth (1950). When the mean temperature for the 24-hour period after anthesis was above 78°F, the pod set was materially reduced. Lima beans showed a similar response although the correlation was not as high since the lima bean was able to set pods satisfactorily at considerably higher temperatures than did the snap bean.

Low night temperatures decreased the number of blossoms and delayed the onset of blossoming (Viglierchio and Went, 1957). Low day temperatures delayed the onset of blossoming but increased the number of blossoms.

Low night temperature (15°C) was favourable to flower formation but not to node formation in beans (Watanabe, 1953 (a)).

In lima beans the weight of pods produced was markedly affected by night temperatures both before and after anthesis (Rappaport and Carolus, 1956).

Controlled temperature experiments indicated that the minimum night temperature was an important consideration, as was the maximum day temperature (Lambeth, 1950).

In general, bean plants showed greater stem growth at higher temperatures (Viglierchio and Went, 1957). Plants grown at cool temperatures (17° day/12°C night) manifested stunting, thick stems, short internodes, and small dark leaves. The plants eventually yellowed and died without flowering. Plants grown at warm temperatures (30^{o} day/$24^{o}C$ night) grew rapidly, developed long internodes, thin stems and small pale leaves. These frail spindly plants did not flower.

With constant temperature treatment the growth of bean plants, in all aspects measured, increased as the temperature increased up to $25^{o}C$ (and for some attributes, up to $30^{o}C$) (Dale, 1964). Growth was not always proportional to the mean temperature, but growth under constant conditions was superior to that under alternating temperatures, having the same mean temperature. Thermoperiodism as proposed by Went (1944) would predict the reverse.

Use of plastic cages to raise the growing temperatures of bush beans for a five-day period after first bloom reduced yields from 22 percent to 67 percent in six plantings (Mack and Singh, 1964). Average maximum temperatures under the perforated polyethylene plastic cages ranged from 84^{o} to $101^{o}F$ for the six plantings while maximum temperatures for controls with no plastic cages averaged 74^{o} to $82^{o}F$.

Soybeans grown in controlled environment cabinets showed that high temperatures and long photoperiods result in increased blossom and young pod drop (Van Schaik and Probst, 1958). No mature pods were produced with a temperature of $60^{o}F$ regardless of the daylength in several varieties of soybeans. Shedding of blossoms was not caused by a lack of viable pollen.

Adverse effect of unfavourable temperature on plant growth were partly or completely prevented by applying essential metabolites to plants (Ketellapper, 1963). The nature of the effective metabolites depended on the species and on the temperature. Vitamin C stimulated the growth of broad beans grown at 30^{o} day and $23^{o}C$ night temperature. The effect of high temperature on peas growing in artificial light was counteracted by sucrose, a vitamin B mixture or riboside mixture, depending on the seed source and temperature conditions.

Under conditions of high respiration, high temperatures, and limited photosynthesis under low light intensity, sucrose sprays on tomatoes gave the greatest dry matter increase (Berrie, 1960). At low temperatures and high rates of photosynthesis the effects of sucrose sprays were negligible.

An increase in soil temperature from 54°F to 78°F was related to increases in dry weight of beans from 60 to 850 percent (Mack, et al., 1964). A similar relationship of phosphorus content of plants was found. Applications of high rates of phosphorus fertilizer did not compensate for the inhibitory effect of the lowest soil temperature (54°F) on the growth of beans.

Beans grown under greenhouse conditions with four moisture levels were found to have significantly different yield responses (Burman and Bohmont, 1961). The higher moisture levels produced a greater weight of beans, number of beans per pot, and number of pods per plant. The highest moisture level (irrigation at 0.5 atmospheres) had a maximum growth rate nearly three times as great as the lowest moisture level (irrigation at 4 atmospheres).

Supplementary irrigation of only 0.5 acre inch at the onset of flowering and 2.0 acre inches split between applications at the onset of flowering and during fruit development in beans increased yields up to 54.7 and 79 percent respectively, and gave more seeds per pod compared with the controls (Gabelman and Williams, 1962). Most of the seeds which developed on moisture-deficient plants were nearest the stigmatic end of the ovary. Pods set late in the season had fewer seeds than those set earlier, regardless of irrigation treatment.

In lima beans, a single irrigation at bloom caused no significant yield increase (Rahn, 1955). When the weather was hot and the relative humidity low at the pod set period, an irrigation appeared to have some value.

Within experimental limits, water relations of the soil-plant complex were considered to have a greater effect on pod set than high temperature (Lambeth, 1950). In all cases, satisfactory pod set was dependent upon maintenance of a favourable moisture supply at the stigmatic surface.

Severe wilting between the time of anthesis and fertilization in beans did not effect the percentage of ovules fertilized although prolonged moisture stress prior to anthesis effected a slight decrease in fertilization (Williams, 1962). Drought influenced fruiting behavior almost exclusively through its effect on processes other than fertilization; short periods of moisture stress, especially during early bloom, induced long lasting changes in subsequent fruiting behavior. The general pattern of abscission found was as follows: unfertilized pods fell first, followed by the last set pods on the plant, followed by a thinning process on each inflorescence, the younger pods falling first.

Three stages of flower abscission were recognized in the runner bean (Iwami, 1951); an early stage, attributed to competition of nutrients between the flowers and the developing plant; a middle stage, attributed to competition for nutrients between flowers; and a late stage, associated with the decline of the plant.

Floral abscission during the initial stages of flowering in lima beans was largely independent of the leaf area, and generally occurred within 48 hours following the hooded bud stage in case of unfertilized flowers (Lambeth, 1950). A minimum of one ovule per pod had to be fertilized and start development to prevent abscission.

In lima beans, the pods at the base of the racemes reduced pod set toward the apical end (Cordner, 1933). Apical pod set could be increased by basal defloration. Early blossoming racemes were more fruitful than later blossoming ones, which stresses the importance of early pod set. Fruit setting followed until "capacity set" was obtained; the remaining reproductive structures were disposed of by abscission.

Failure to obtain a capacity set with large-seeded lima beans was most frequently due to lack of fertilization of the egg cells (Lambeth, 1950). The expression of climatic and edaphic factors on pod set was primarily through pollen tube growth and fertilization.

Pod set and yield were considered to be not necessarily comparable since blossom, bud, and pod abscission may occur later in the blossoming period as a result of the competition for essential metabolites (Lambeth, 1950). If the capacity set was obtained during the first two weeks after blossoming, the yield was considered to be dependent primarily on the "active" leaf area and light conditions.

In beans, yield was not correlated with the number of blossom per plant (Binkley, 1932). There was also a negative correlation between the percent blossom and pod drop and yield per plant.

Domestic marketability harvest curves suggested that fruit production may be cyclic in pole beans (Viglierchio and Went, 1957). The frequency of the cycle appeared to increase as the night temperature increased.

In three bean varieties there was a highly significant correlation between increasing age and decreasing percent set of pods (Smith and Pryor, 1962). There was also a highly significant correlation between increasing temperature and decreasing pod set, in two of the varieties used.

After the plants began to set fruit, there was a steady decrease in the percentage of blossoms that set fruit, until the setting capacity was reached (Schrader, 1943).

Side dressings of nitrogen fertilizers applied to beans increased the percentage pod set, however, additional nitrogen applied during blossoming decreased pod set, which emphasized the importance of timely application in fertilizer practice (Lambeth, 1950).

In lima beans plants with good pod set had substantially higher concentrations of nitrate nitrogen, potassium, available calcium and magnesium, but less phosphate in the stems than plants with poor pod set (Wolf, 1942). The concentrations of nitrate and available calcium were closely associated with pod set. When the concentration of nitrate and available calcium in the stem was above 2250 and 9000 ppm, respectively, the plant had a good set of pods and when the concentration was below 1250 and 6000 ppm, respectively, the plant had a poor set of pods.

A reduction in light intensity lowered the assimilation ability in snap bean plants (Inoue and Suzuki, 1956). At less than 30 percent natural light (no light intensities were given by the authors) growth was markedly checked. As the light intensity was reduced the number of latent flower buds increased and the number of blossoms decreased. Severe restrictions of light intensity resulted in the increase of flower bud drop and the reduction of blossom number. Pod number was reduced to half that in the control plot. The reduction in light intensity had almost no effect on pollen germination.

When light intensity was reduced by shading with cheesecloth without markedly affecting the temperature (20^{o}F), tomatoes doubled their growth and fruiting response (Johnson and Hall, 1955). Factors other than low carbohydrate content limited fruiting in tomatoes under conditions of high temperature and light intensity. Reduced pod set was not due to the inability of conductive tissue to translocate carbohydrates.

Net uptake of carbon dioxide in bean plants at light intensities above the compensation point was not markedly influenced by temperature (Ormrod, 1964). Net losses of respiratory carbon dioxide at the lower light intensities and in darkness were markedly affected by temperature with uniformly increasing losses of carbon dioxide with increasing temperature.

Bean pistils became receptive three days before anthesis, and the percentage fruit set increased until the day before anthesis (Inoue and Suzuki, 1959). If the style was cut one hour after pollination, the fruit set was low (approximately 20 percent), but increased with delayed time of cutting and was low at high temperatures. Potted plants placed under constant temperatures for four hours after pollination had no pods at 10^o and 45^oC, a few pods between 30^o and 40^oC, and a good pod set between 15^o and 25^oC. Potted plants placed under constant temperatures four hours before pollination had no pods at 10^o and 45^oC but in the 15^o to 40^oC range, there were no significant differences between temperatures.

Beans flowered normally from midnight to sunrise (Watanabe, 1953 (b)). Day and night temperature affected flowering, pod set being decreased by high evening temperatures. Pollen activity was highest at anthesis and 10 hours before it. Pollen germination and pollen tube growth were favoured by damp conditions and moderate temperatures, the optimum being 94 to 100 percent relative humidity and 20 to 25^oC.

Germination of bean pollen was recognizable the afternoon before flowering, but the percentage germination increased toward the time of anther-dehiscence (anthesis occurred mainly between 5:00 and 7:00 a.m. (Inoue, 1955)), and then decreased rapidly and the pollen grains almost lost their vitality 5-6 hours after anthesis (Inoue and Shibuya, 1954). The optimum <u>in vitro</u> temperature for pollen germination was 20^o to 25^oC and the optimum relative humidity 80 percent. When bean plants were treated with temperatures between 25° to 30°C, the germinability was greatly reduced, compared to the optimum temperature.

The optimum in vivo temperature for pollen germination was 15°C and the critical temperature 30°C (Ahmadi, 1956). At 32.2°C blossoms dropped from intact plants, but not at 21.1°C. Anatomical studies showed that abscissed flowers were not fertilized. Blossom abscission of the dry beans under adverse conditions was probably due to the inability of the pollen grains to germinate.

Long-sustained high temperature (30°C) and high night temperature before pollen mother cell reduction division in beans resulted in abnormal flowers, most of which had abortive pollen (Watanabe, 1953 (a)).

Proper germination of the pollen grain was dependent upon a relatively high sugar concentration (10 percent or more), boron (which may reach as much as one percent of the total ash content of the stigmatic exudate), gibberellins, and others as yet, ill-defined factors (Nitsch, 1962).

In tomatoes, two responses correlated with higher temperature were associated with parthenocarpy (Johnson and Hall, 1954). The first was a tendency for many varieties to exhibit style exsertion and the second involved a loss of pollen viability at temperatures above 90°F. Thus, if either condition was present, fertilization was either reduced or did not occur, and any fruits that developed were partially or entirely seedless.

Pollen grains contain auxins (Leopold, 1955). When pollination occurs, there is a great increase in auxin content in the ovaries. Without pollination such an increase is entirely lacking. The increase in auxin level in the ovary at the time of pollinated fruit-set is too great to be accounted for simply on the basis of the auxin supplied by the pollen itself. Evidence indicates that the enzymatic production of auxin is activated by pollination, possibly by increased availability of some precursor of auxin. As much as one hundred times more auxin is formed in the ovary than is presented to the ovary by the pollen. This new supply of auxin in the ovary stimulates overall plant growth. Natural parthenocarpy takes place in ovaries which have naturally high auxin contents. Flower ovaries can often be artificially induced to set parthenocarpic fruit by the application of auxins.

Fruit-set requires more than auxin alone (Leopold and Scott, 1952). There is a requirement for organic nutrients or substrates for growth. When all mature leaves of tomato plants were removed from the plant there was no fertilized or parthenocarpic fruit-set. As the number of mature leaves increased, there was a quantitative increase in fruit-set. Artificially-induced parthenocarpic fruit had a lower leaf requirement than fruit-set by pollination.

When 0.4 percent indolebutyric acid was applied to open blossoms of Fordhook bush lima beans there was a significant decrease in pod set (Schrader, 1943).

The application of Parmone as a dust containing naphthaleneacetic acid (NAA) to bush beans in three applications at one-week intervals during the blossoming period significantly reduced the number of pods set (Hardenburg, 1944).

In beans the greatest increase in yield (59 to 72 percent) was obtained from NAA and beta-naphthoxyacetic acid sprays under high temperature, a fair increase (6 to 19 percent) when the weather was moderately warm, and a decrease under cool temperatures (Murneek, _et al._, 1944). The increase in yield under high temperatures was due to increase in pod set and size.

Wax beans with two applications of dusts at blossoming, containing NAA at 40 and 80 ppm gave a 24 and 12 percent yield increase, respectively (Fisher, <u>et</u> <u>al</u>., 1946). A decrease in yield was noted with dusts at 160 ppm. The increase in yield was due to a greater number of small pods rather than larger pods.

When low concentrations of 2, 4, 5-trichlorophenoxyacetic acid were applied to lima beans at blossoming, almost all their blossoms dropped and the plant ceased to grow vegetatively for a period of 20 to 30 days (Marth and Wester, 1954). After the plants resumed growth they developed more axillary branches than controls and were very bushy in appearance. Pods on the sprayed plants matured late and when no frost interfered, the sprayed plants produced 18 to 35 percent more fresh marketable pods than did the controls. Untreated plants on which early blossoms had been removed by hand produced 33 percent more pods than the controls, but the plants themselves were no larger than the controls.

When 10 to 20 ppm of 2,4-dichlorophenoxyacetic acid (2,4-D) was applied to two-week old bean seedlings or 10 ppm of 2,4-D to four-week old seedlings, the initial effect was to stop all further development for 10 to 14 days (Wedding, <u>et</u> <u>al</u>., 1956). When the plant resumed normal growth, the new leaves were twisted and otherwise deformed showing typical 2,4-D induced effects. The plants developed more slowly and usually had a bushy, stunted appearance. The appearance of blossoms was delayed on the treated plants but ultimately developed in greater abundance than on untreated plants, possibly due to increased branching. The treated plants also produced a larger set of pods. Later treatments and higher concentrations tended to further delay both floral initiation and maturity of the fruit. Alpha-ortho-chlorophenoxypropionic acid and N-meta-tolylphthalamic acid offered promise in preventing fruit drop in beans when applied over the blossoms.

Growth inhibition of bean plants caused by 2,4-D can be reduced by using iron in the chelated form as ferric-ethlylenediaminetetraacetate (FeEDTA) with the 2,4-D (Wort, 1962).

When field beans were sprayed 14 days after emergence with high concentrations of 2,4-D (100 ppm) together with $FeSO_4$ (300 ppm Fe), there were no inhibitory effects on plant growth, number of pods set per plant, seed size, yield of dry beans and dry matter yield 93 days after treatment (Miller, et al., 1962). Delayed maturation was observed at 2,4-D levels greater than 5 ppm, and with added Fe the delay was prolonged further. In all cases where 100 ppm 2,4-D along adversely affected vegetative and reproductive development of beans, the foliar application of $FeSO_4$ either overcame the inhibitory effects.

A significant reduction in bush bean yield occurred following application of a foliar spray combining 1 ppm 2,4-D and 100 ppm maleic hydrazide (Mack, 1963). Treatments of 1 ppm 2,4-D alone or in combination with an iron chelate, produced no significant differences in yield when compared to a control. Foliar sprays were applied to plants when the primary leaf was one-half to three-fourths expanded in size.

In tomatoes the abscission of normal flowers occurred at time when the vegetative growth was at a high level, (Johnson, 1956). A high level of auxin existed and in moving to the abscission zone offset the effect of the auxin moving from the fertilized flower. The flower then falls, according to the auxin gradient theory proposed by Addicott, et al., (1955). At a low concentration of 2,4-D (1 ppm) applied distally to the abscission zone generally prevented abscission in excised flowers (Johnson, 1956), whereas the same concentration applied proximal to the zone induced abscission. However, at a higher concentration (10 ppm), applications on either side of the zone tended to prevent abscission.

Work with bean leaf explants showed that there was a two-phase action of auxins on abscission (Briggs and Leopold, 1958). The primary action of auxins was directly on the abscission zone and was of the two-phase type with low concentrations accelerating and high concentrations inhibiting abscission. The differences between proximal and distal applications of auxins could be explained on the basis of differences in transport, without the necessity of an auxin gradient involvement.

Lygus bugs, by "toxic" feeding, caused a shedding of blossoms and young pods up to two inches long in lima beans (Baker, et al., 1946). The young pod commonly turned yellow, withered and dropped, these were referred to by growers as "buckskins" and attributed to high temperature.

Various insects, especially Lygus bugs, induced bud, blossom, and small pod drop, and distorted and dwarfed the small leaflets of bean plants (Fisher, et al., 1946). Some of the loss was prevented by dusting with NAA applied at blossoming.

The optimum plot sizes for total yield, number of pods and earliness in lima beans were found to be 15.0, 26.2 and 24.4 square feet respectively, when rows were planted three feet apart (Holle and Peirce, 1960). Single or double row plots gave approximately equal efficiency for number of pods and earliness. A single row plot was required to satisfy the optimum plot requirement for total yield. Earliness data showed low coefficient of variability in all combinations of plot and block dimensions. Data suggested that no replication was required to measure earliness. Extensive replication was required for effective evaluation of total yield and number of pods.

MATERIALS AND METHODS

Two types of experiments were conducted, controlled-environment studies and field experiments.

I. Controlled-Environment Studies.

A. Temperature Effects on Growth and Fruiting.

The present experiments of temperature effects on the growth and flowering behavior of beans were conducted in controlled-environment growth cabinets (Ormrod, 1962). Day and night temperatures were controlled to $2^{\circ}F$, using separate thermostats. Light was supplied by standard bipin fluorescent tubes (2/3 Sylvania Lifeline cool white reflector and 1/3 Sylvania Gro-Lux) with a light intensity of approximately 2000 foot-candles (read with a Weston Model 756 illumination meter without cosine filter) at a distance equivalent to half the distance between the top of the plant and soil surface. The photoperiod was 16 hours. There was no humidity control.

One-gallon plastic pots with drain holes were filled with a fertile soil. A three-fourths inch layer of peat moss was placed on the soil to reduce water loss due to evaporation. A three-fourths inch layer of gravel or sand was placed at the bottom of each pot to facilitate subirrigation.

In the first experiment eight Stringless Green Pod bush bean seeds were sown in each pot and seedlings were thinned later to four uniform plants. In the other experiments four seeds were sown in each pot and seedlings were later thinned to one plant. Temperature treatments were imposed from seeding.

The pots were randomly placed on aluminum pans in the controlled-environment growth cabinets. The plants were watered from the top or by sub-irrigation. The position of the plants was frequently moved to minimize accumulated micro-climate effects due to location in the cabinet.

When blossoming commenced, in all experiments but the first, each blossom was labelled to show date of blossoming.

There was no fixed time for harvest, since the effect of temperature on blossom drop was considered more important for the purposes of this study than the effect of temperature on the yield of pods, leaves and stems.

For statistical comparisons, pots were used as experimental units. For all experiments there were eight pots per treatment, except Experiment 3, which had four pots per treatment.

The experiments conducted were as follows:-

Experiment 1. Effects of Variable Day and Constant Night Temperature.

a) 90° day and 60°F night.

b) 80° day and 60°F night.

c) 70° day and 60°F night.

This experiment was conducted to determine an effective temperature range for blossom drop studies. The pods were harvested at optimum marketable maturity, that is when 15 percent of pods were more than 27/64 inch diameter at the thickest portion of the pod. The average of the four plants was used in all comparisons between treatments.

Experiment 2. Effects of Variable Day and Variable Night Temperature.

a) 95° day and 80°F night.

b) 85° day and 70°F night.

c) 75° day and 60°F night.

When the pods reached marketable maturity (21-24/64 inch), the pods on one-half of the eight plants in each temperature regime were picked. The pods on the other four plants were allowed to ripen.

Experiment 3. Effects of Constant Day and Variable Night Temperature.

a) 95° day and 80°F night.

b) 95° day and 70°F night.

c) 95° day and 60°F night.

This experiment was repeated to provide additional information on blossom and young pod drop.

Experiment 4. Repetition of Experiment 3.

This experiment was terminated when complete observations of blossom and young pod drop for the first 15 days of blossoming were made.

Experiment 5. Effects of Variable Day and Constant Night Temperature.

a) 95° day and 60°F night.

b) 85° day and 60°F night.

c) 75° day and 60°F night.

This experiment was terminated when complete observations of blossom and young pod drop for the first 15 days of blossoming were made.

B. <u>Light Intensity Effects on Growth and Fruiting</u>.

Experiment 6.

The experiment was conducted in a Percival controlled-environment cabinet. Three light intensities were used: 4000, 2700, 1900 foot-candles at plant level. The lights used were very high output cool white fluorescent tubes. The temperature was 80°F day and 70°F night, with a 16-hour photoperiod. The plants were prepared as in the temperature study experiments, with one plant per pot and four pots per treatment. Each blossom was individually labelled to show date of blossoming. The plants were harvested when the pods reached optimum marketable maturity.

Observations of Low Temperature Effects.

Observations were made of plants grown in Percival controlled-environment cabinets with day temperatures of 55° or 45°F, and night temperature of 40°F. The light intensity was approximately 1100 foot-candles at plant level. The photoperiod was 16 hours.

II. Field Studies.

General Procedures.

Field experiments were conducted at the University of British Columbia, Vancouver, B.C. (Alderwood sandy loam) and at the Canada Department of Agriculture Experimental Farm at Agassiz, B.C. (Monroe silt loam) to compare location effects on the fruiting response in beans. Both pole and bush beans were used in these experiments.

All experiments with pole beans used the variety Blue Lake FM1. Six varieties of bush beans were studied; Stringless Green Pod, Tendercrop (Asgrow), Tendercrop (Buckerfield's), Bush Blue Lake (Asgrow #274), Bush Blue Lake OSU 949-1864-2, Bush Blue Lake BLS (Seed Research Specialists) and Asgrow Early Wax.

Except for the row spacing studies, all pole beans were planted in rows five feet apart. The seed was sown four to five seeds per foot. In bush beans, the rows were planted three feet apart with nine seeds per foot.

At Agassiz, all the rows were planted north and south. At the University of British Columbia except for the row direction experiments, the rows were planted east-north-east to west-south-west.

Except for the nitrogen experiment, all beans received 500 pounds of 6-27-25 fertilizer per acre at seeding. The fertilizer was banded $1\frac{1}{2}$ inches to the side and $1\frac{1}{2}$ inches below the seed.

In all plots, except the planting date experiment, weeds were controlled by the application of "Premerge" (Dow Chemical Co.) at the rate of 3.6 pounds per acre in 30 gallons of water, at the "hypocotyl hook" stage. Additional weed control was done by one machine cultivation and hand hoeing. In the planting date experiment, all weeds were controlled by machine cultivation and hand hoeing. The pole beans were staked.

In all pole bean experiments, the experimental units were ten feet by five feet, except in the row spacing studies, and in all bush bean experiments, 10 feet by three feet. There were five replicates per treatment in all field experiments. In all experiments, except Experiment 7, a randomized complete block design was used.

At harvest, the centre six feet of row (30 square feet plot) in pole beans, and the centre eight feet of row (24 square feet plot) in the bush beans were harvested from each experimental unit. Data were collected on number and fresh weight of pods when pods were approximately 21/64-27/64 inch in diameter at the thickest portion of the pod, for all pole bean experiments. Bush beans were harvested when approximately 15 percent of the pods were more than 27/64 inch in diameter at the thickest portion of the pod.

A. <u>Pole Bean Experiments at the University of British Columbia</u>.

Experiment 7. Effect of Planting Date on the Fruiting Response.

Five different planting dates were studied; May 1, 15, 29, June 12 and 26. A Latin square experimental design was used.

Experiment 8. Effect of Nitrogen Level on the Fruiting Response.

Three levels of nitrogen were supplied:
0, 30 and 60 pounds per acre of available nitrogen as ammonium nitrate. One hundred eighty five pounds per acre of available phosphorus as superphosphate and 175 pounds per acre of available potassium as KCL were applied to all experimental units.

Blossom drop counts were made each week by gathering abscissed blossoms and young pods.

Experiment 9. Effect of Row Spacing on the Fruiting Response.

Three row spacings were studied; two feet, four feet and eight feet.

Experiment 10. Effect of Row Direction on the Fruiting Response.

The row direction experiment was set up in two directions; with the prevailing winds, east-north-east, west-south-west, and at right angle to the prevailing winds, north-north-west to south-south-east.

Experiment 11. Effect of Chemical Sprays on the Fruiting Response.

Nine treatments and one control were used; Indoleacetic acid (IAA) at 10 and 100 ppm, NAA at 10 and 100 ppm, sucrose at 1 and 20%, 2,4-D at 1 and 10 ppm and 2,4-D at 10 ppm with FeEDTA at 5 ppm. The 100 mg. NAA and 10 mg. 2,4-D were first dissolved in 30 and 5 ml. of ethanol respectively, before being diluted in a 1000 ml. of distilled water. A "spreader" was used with all sprays.

Blossom drop counts were made each week.

B. Bush Bean Experiments at the University of British Columbia.

Experiment 12. Effect of Chemical Sprays on the Fruiting Response.

Three varieties of bush beans were used; Stringless Green Pod, Tendercrop and Bush Blue Lake Asgrow #274. The treatments were the same as for the pole beans at the University of British Columbia.

Blossom drop counts were made each week for the centre two feet in each plot. At harvest, only the fresh weight of pods was recorded.

Experiment 13. Effect of Variety on the Fruiting Response.

The varieties, Bush Blue Lake OSU 949-1864-2, Bush Blue Lake Asgrow #274, Bush Blue Lake BLS (Seed Research Specialists), Stringless Green Pod, Tendercrop (Buckerfield's), Tendercrop (Asgrow) and Asgrow Early Wax were used. A two-foot row section in the centre of each plot was used to determine the blossom drop. The number (graded to size visually) and fresh weight of pods and the number of plants were determined from the centre eight feet of each plot.

C. Pole Bean Experiment at Agassiz.

Experiment 14. Effect of Chemical Sprays on the Fruiting Response.

Seven treatments and one control were used; IAA at 10 and 100 ppm, NAA at 10 and 100 ppm, sucrose 1% solution, and 2,4-D at 1 and 10 ppm. Blossom drop was counted each week.

D. Bush Bean Experiment at Agassiz.

Experiment 15. Effect of Chemical Sprays on the Fruiting Response.

Tendercrop beans were used, and the sprays were the same as on the pole beans at Agassiz. Blossom drop (weekly counts) and number of pods were determined for the centre two feet of row in each plot. Fresh weights of pods were determined at harvest.

Data obtained in all experiments was statistically evaluated using analysis of variance methods followed by Duncan's multiple range tests. Most of the statistical analyses were carried out using the I.B.M. 7040 computer (U.B.C. Computing Centre).

In the presentation of results and in discussion only those differences which were significant at the 5 percent level were considered to be meaningful and worthy of comment.

RESULTS

I. Controlled-Environment Studies.

In Experiment 1 the leaf weight was inversely related to the temperature (Table 1). As the temperature increased from 70/60°F to 80/60°F to 90/60°F, the fresh and dry weight of the leaves decreased. There was no difference in response between the fresh and dry weight of the stems. The height of the plants was greater at 90/60°F than at the other two temperatures. At the highest temperature the plants were taller than at lower temperatures. There was no difference in node number between the lower temperatures but at 90/60°F there were fewer nodes. There was no difference in pod number and weight between the two lower temperatures, but at 90/60°F there were fewer pods and the pod weight was less.

In Experiment 2, when the pods were harvested at marketable maturity (final harvest was three months after planting), the leaf weight was inversely related to the temperature (Table 2). As the temperature increased from 75/60°F to 85/70°F to 95/80°F, the fresh and dry weight of leaves decreased. At the higher temperature, 95/80°F there was less fresh and dry stem weight than at lower temperatures. The height of the plants grown at 95/80°F was less than at lower temperatures but the number of nodes was unaffected. The pod weight was similar at the two lower temperatures but at the high temperature pod weight was less than at lower temperatures. There were more blossoms at 85/70°F than at 75/60°F but at 95/80°F there was a decrease in number of blossoms compared to lower temperatures.

Table 1. Effect of 90/60, 80/60, and 70/60°F day/night temperatures on growth and fruiting of Stringless Green Pod bush beans in Experiment 1.

Temperature °F	Leaf Weight Fresh (gm.	Leaf Weight Dry (gm.)	Stem Weight Fresh (gm.)	Stem Weight Dry (gm.)	Height Total (in.)	Nodes (number)	Pod Weight Fresh Marketable (gm.)	Pod Weight Fresh Total (gm.)	Pod Weight Dry Total (gm.)	Pods (number) Marketable	Pods (number) Total
90/60	11.3c*	1.35c	9.2a	1.50a	16.4a	8.3b	7.7b	8.6b	0.96b	3.0b	5.3b
80/60	13.4b	1.63b	9.0a	1.52a	14.1b	9.3a	18.0a	19.2a	1.92a	5.3a	8.0a
70/60	15.8a	1.93a	9.2a	1.80a	13.8b	9.1a	21.1a	21.5a	2.07a	6.0a	7.6a

* means followed by the same letter are not significantly different at the 5% level (Duncans multiple range test).

Table 2. Effect of 95/80, 85/70, 75/60°F day/night temperatures and harvest time on growth and fruiting of Stringless Green Pod bush beans in Experiment 2.

	Temp. °F	Leaf Weight Fresh (gm.)	Leaf Weight Dry (gm.)	Stem Weight Fresh (gm.)	Stem Weight Dry (gm.)	Height Total (in.)	Nodes (number)	Pods Weight Fresh (gm.)	Pods Weight Dry (gm.)	Blossoms Total (number)	Pods Set (number)	Blossoms Dropped (number)
Marketable Maturity Harvest	95/80	26.6c	4.40c	41.6b	8.34b	13.5b	11.2a	1.0b	0.14b	25.0c	2.2b	22.8b
	85/70	94.1b	13.14b	65.8a	16.22a	19.8a	10.8a	111.6a	10.45a	102.5a	52.8a	49.8a
	75/60	125.5a	17.06a	65.1a	16.77a	17.9a	9.8a	129.3a	11.07a	67.8b	41.8a	27.0b
Dry Maturity Harvest	95/80	51.4a	6.46a	41.8a	6.40a	13.0b	11.0a		0.11b	24.0b	2.0b	22.0a
	85/70	22.6b	2.90b	24.4c	4.57b	18.6a	10.2ab		13.58a	42.8a	14.2a	28.5a
	75/60	50.6a	5.41a	32.6b	5.53ab	20.1a	9.2b		14.90a	42.2a	13.5a	28.8a

First 15 Days of Blossoming	Temperature °F	Blossoms Total (number)	Pods Set (number)	Blossoms Dropped (number)	Blossoms Dropped (%)
	95/80	14.6b	0.1b	14.5b	99.5a
	85/70	46.8a	16.4a	30.4a	65.1b
	75/60	43.9a	17.0a	26.9a	61.4b

The number of pods set was reduced at temperatures above 85/70°F. There was no difference between the number of blossoms that dropped at 95/80°F and 75/60°F but there were more blossoms at 85/70°F.

In Experiment 2 when the pods were harvested at dry maturity (harvested two months after planting) there was no difference in fresh and dry weight of leaves between 95/80°F and 75/60°F but at 85/70°F the fresh and dry weight of the leaves was less than at the other temperatures. The fresh weights of stems in all treatments were different, with the highest temperature giving the greatest weight, followed by 75/60°F and the lowest weight at 85/70°F. There was no difference in dry weight of stems between 95/80°F and 75/60°F, and no difference between 85/70°F and 75/60°F, but at 95/80°F stems were heavier than at 85/70°F. The height of the plants grown at 95/80°F was less than at lower temperatures. There was no difference in the number of nodes between 95/80°F and 75/60°F but plants grown at 95/80°F had more nodes than plants grown at 75/60°F. There were no differences in pod dry weight, total blossoms and pods set between the lower two temperatures, but at 95/80°F there were fewer pods set than at the lower temperatures. There were no differences in number of blossoms that dropped at all three temperatures.

When the first 15 days of blossoming at all temperatures were compared there were no differences in total blossoms, pods set, blossoms dropped and percentage blossoms dropped between 85/70°F and 75/60°F, but these two temperature regimes had greater numbers of blossoms and more pods set than at 95/80°F.

When plant were harvested at marketable maturity, the blossoming pattern was found to be cyclic (Fig. 1, 2, and 4). The first cycle had the greatest number of flowers, but subsequent cycles had a greater percentage of pod set. The plants remained vigorous, and at 85/70°F and 75/60°F plants showed increased growth (Table 2).

When plants were harvested at dry maturity only one blossoming occurred followed by senescence of the entire plant (Fig. 3 and 5).

In Experiment 3 there were no differences between 95/80°F and 95/60°F or between 95/80°F and 95/90°F in fresh weight of leaves but 95/60°F plants had more leaf fresh weight than plants grown at 95/70°F (Table 3). Plants grown at 95/80°F and 95/70°F had the same dry weight of leaves but plants grown at 95/80°F had a higher dry weight of leaves. Plants grown at all temperatures had similar fresh and dry weight of stems. The height of the plant varied inversely with the night temperature, with the plants grown with cooler nights being taller than those grown at the high night temperature. There were similar numbers of nodes per plant at all temperatures. The lowest night temperature resulted in a higher yield of pods (fresh and dry) than the higher night temperatures. The highest night temperatures resulted in a reduced number of blossoms, pods set and number of blossoms dropped per plant compared to lower night temperatures.

Results of Experiment 4 were very similar to those of Experiment 3 for which the same temperatures were used except that at the higher night temperatures no pods set (Table 4 shows blossoming data only). There was a decrease in percent blossoms dropped at the lower night temperatures.

In Experiment 5 plants at 95/60°F, 85/60°F and 75/60°F had similar numbers of pods but there was a reduction of pods set at the 95/60°F temperature (Table 5). The number of blossoms that dropped and the percent blossoms dropped was highest at the highest day temperature.

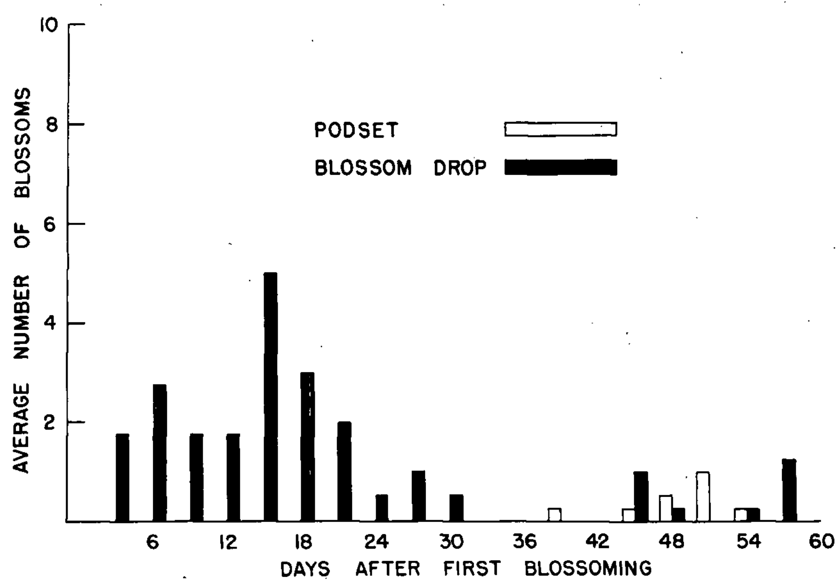

Figure 1. Effect of 95/80°F day/night temperatures on the blossoming pattern of Stringless Green Pod bush beans. No mature pods had developed.

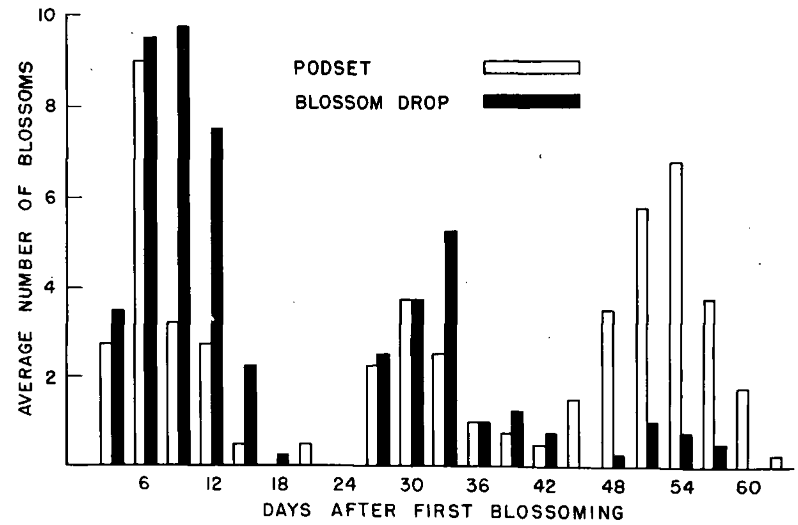

Figure 2. Effect of 85/70°F day/night temperatures on the blossoming pattern of Stringless Green Pod bush beans when pods were harvested at marketable maturity.

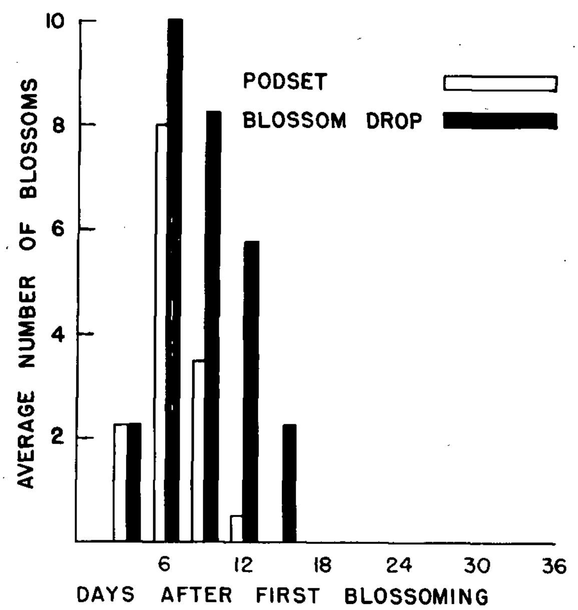

Figure 3. Effect of 85/70°F day/night temperatures on the blossoming pattern of Stringless Green Pod bush beans when pods were harvested at dry maturity.

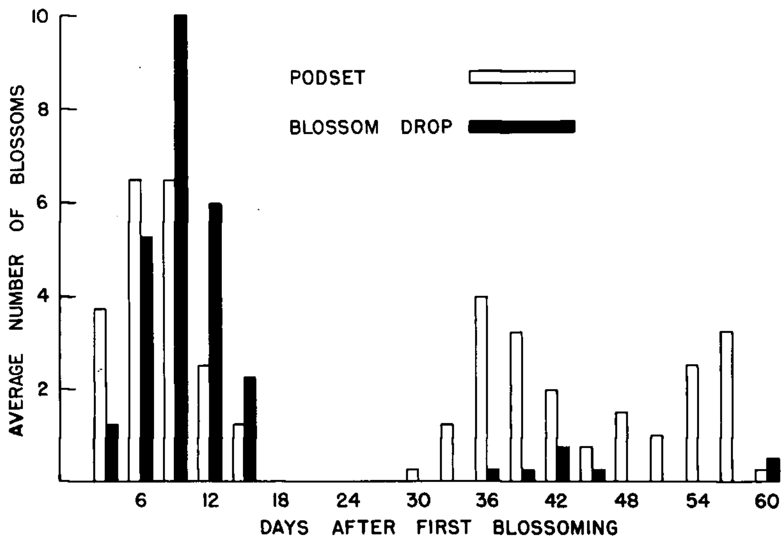

Figure 4. Effect of 75/60°F day/night temperatures on the blossoming pattern of Stringless Green Pod bush beans when pods were harvested at marketable maturity.

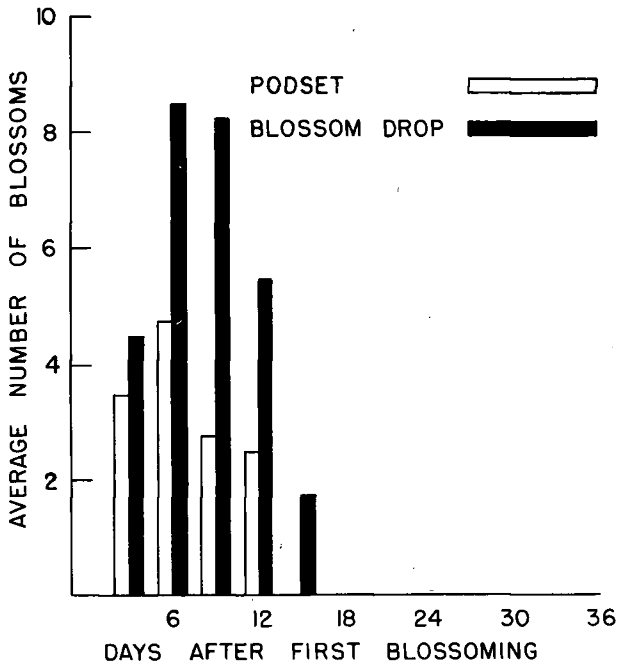

Figure 5. Effect of 75/60°F day/night temperatures on the blossoming pattern of Stringless Green Pod bush beans when pods were harvested at dry maturity.

Table 3. Effect of 95/80, 95/70, 95/60°F day/night temperatures on the growth and fruiting of Stringless Green Pod bush beans in Experiment 3. Marketable maturity single harvest.

Temperatures °F	Leaf Weight Fresh (gm.)	Leaf Weight Dry (gm.)	Stem Weight Fresh (gm.)	Stem Weight Dry (gm.)	Height Total (in.)	Nodes (number)	Pods Weight Fresh (gm.)	Pods Weight Dry (gm.)	Blossoms Total (number)	Pods Set (number)	Blossoms Dropped (number)
95/80	55.8ab	6.55b	31.8a	5.84a	12.8b	8.5a	0.4b	0.06b	13.8b	1.0b	12.8b
95/70	51.6b	6.55b	32.8a	6.40a	14.8a	9.0a	2.2b	0.32b	36.5a	4.8a	31.8a
95/60	64.4a	8.37a	29.8a	6.16a	14.9a	8.8a	8.8a	0.96a	41.0a	11.0a	30.0a

Table 4. Effect of 95/80, 95/70, 95/60°F day/night temperatures on fruiting of Stringless Green Pod bush beans in Experiment 4. First 15 days of blossoming.

Temperatures °F	Blossoms Total (number)	Pod Set (number)	Blossoms Dropped (number)	Blossoms Dropped (percent)
95/80	13.8b	0.0b	13.8b	100.0a
95/70	24.6a	0.0b	24.6a	100.0a
95/60	31.0a	1.5a	29.5a	95.4b

Table 5. Effect of 95/60, 85/60, 75/60°F day/night temperatures on fruiting of Stringless Green Pod bush beans in Experiment 5. First 15 days of blossoming.

Temperatures °F	Blossoms Total (number)	Pods Set (number)	Blossoms Dropped (number)	Blossoms Dropped (percent)
95/60	26.5a	0.2b	26.3a	99.2a
85/60	26.8a	13.0a	13.8b	49.0b
75/60	29.0a	15.2a	13.8b	46.9b

In Experiment 6 fresh and dry leaf weight, fresh stem weight, fresh and dry pod weight, total blossoms and blossom drop were all similar at the 4000 and 2700 foot-candles light intensities, but were reduced at the 1900 foot-candles light intensity (Table 6). Dry stem weight varied directly with the light intensity. Height and number of nodes were not affected by light intensity. Plants grown at 4000 and 2700 foot-candles had more pods set than those growing at the lower light intensity.

Plants grown at 55/40°F resulted in stunted growth. The number of nodes and the total height were lower than all other temperature regimes. A few blossoms formed, but none set pods.

Seeds planted at 45/40°F did not germinate.

II. Field Studies.

In Experiment 7, the number and weight of pods were similar for the first three planting dates (Table 7). Number of pods and yields were lower at the last two planting dates compared to earlier planting dates.

In Experiment 8, the level of nitrogen fertility had no effect on the number and weight of pods, number of blossoms dropped or the number of plants per plot (Table 8).

In Experiment 9, the number and weight of pods varied directly with the row spacing (Table 9). The wider the rows apart, the greater the yield per unit length of row. However, if the data were adjusted for area, the narrower row spacings gave the greatest yield. The number of plants per plot was similar at all row spacings.

In Experiment 10, row direction had no effect on the number and weight of pods, or the number of blossoms that dropped (Table 10).

In Experiment 11, plants sprayed with IAA (100 ppm), sucrose (20%) and the control had similar numbers of pods (Table 11). Only 2,4-D

Table 6. Effect of light intensity on the growth and fruiting of Stringless Green Pod bush beans with 80/70°F day/night temperature in Experiment 6. Marketable maturity single harvest.

Light Intensity (ft.-ca)	Leaf Weight Fresh (gm.)	Leaf Weight Dry (gm.)	Stem Weight Fresh (gm.)	Stem Weight Dry (gm.)	Height Total (in.)	Nodes (number	Pods Weight Fresh (gm.)	Pods Weight Dry (gm.)	Blossoms Total (number)	Pods Set (number)	Blossoms Dropped (number)
4000	73.3a	9.08a	53.8a	10.53a	18.6a	8.0a	98.0a	10.54a	95.0a	32.8a	62.2a
2700	67.9a	7.36a	45.8a	7.10b	20.8a	7.5a	86.6a	8.19a	73.0a	21.5ab	51.5a
1900	48.4b	4.64b	25.6b	3.98b	18.5a	8.0a	42.8b	3.97b	35.8b	13.2b	22.5b

Table 7. Effect of planting date on the fruiting of Blue Lake FM1 pole beans at the University of B.C. in Experiment 7.

	Pods Number	Pods Weight (gm.)
May 1	974a	5171a
May 15	996a	5052a
May 29	1123a	5521a
June 12	743b	3281b
June 26	336c	1214c

Table 8. Effect of nitrogen on the fruiting response of Blue Lake FM1 pole beans at the University of B.C. in Experiment 8.

Nitrogen Supplied	Pods Total (number)	Pods Weight (gm.)	Blossoms Dropped (number)	Plants (number)
0 pounds	1045.0a	5339a	46.8a	20.0a
30 pounds	1013.6a	5169a	37.8a	19.8a
60 pounds	994.6a	5124a	40.6a	19.6a

Table 9. Effect of row spacing on the fruiting response of Blue Lake FM1 pole beans at the University of B.C. in Experiment 9.

Row Spacing	Pods Number Total	Pods Number Adjusted for area	Pods Weight (gm.) Total	Pods Weight (gm.) Adjusted for area	Plants Number
2 Foot	484.2c	1936.8a	2930c	11600a	23.8a
4 Foot	775.8b	1551.6b	4153b	8307b	23.6a
8 Foot	972.4a	972.4c	5230a	5230c	22.6a

Table 10. Effect of row direction on the fruiting response of Blue Lake FM1 pole beans at the University of B.C. in Experiment 10.

	Pods Total (number)	Pods Weight (gm.)	Blossoms Dropped (number)
East-north-east to west-south-west	805.6a	5205a	53.0a
North-north-west to south-south-east	794.8a	5109a	51.6a

Table 11. Effect of chemical sprays on the fruiting response of Blue Lake FM1 pole beans at the University of B.C. in Experiment 11.

Chemical Sprays	Pods (number)	Pods Weight (gm.)	Blossoms Dropped (number)
IAA - 10 ppm	1032.6d	5353cd	92.8de
- 100 ppm	1056.0cd	5538bc	148.8b
NAA - 10 ppm	928.2e	5071e	129.0bc
- 100 ppm	475.8g	2647h	234.4a
Sucrose - 1 %	1035.6d	5257de	109.8cd
- 20 %	1112.4b	5712b	108.6cd
2,4-D - 1 ppm	1190.0a	5707b	135.4bc
- 10 ppm	781.4f	4821f	73.2e
2,4-D - 10 ppm & FeEDTA 5 ppm	771.2f	4514g	78.6e
Control	1085.0bc	5965a	132.0bc

sprayed at 1 ppm increased the number of pods. All other chemical sprays caused reductions innumbers of pods. All treatments reduced pod weight compared to the control. The higher concentrations of 2,4-D and NAA greatly reduced the yield. IAA (10 ppm) and 2,4-D (10 ppm and 10 ppm with FeEDTA 5 ppm) sprayed plants showed reduced blossom drop. Only NAA (100 ppm) showed an increased blossom drop. Blossom drop in other treatments was similar to the control.

In Experiment 12, plants sprayed with IAA (10 ppm) sucrose (20%) and the control had similar weights of pods for the variety Stringless Green Pod (Table 12). Only NAA (100 ppm) reduced the yield. Other sprays resulted in increased weight of pods compared to the control. The number of blossoms that dropped in all treatments were similar.

In Tendercrop bush beans IAA (10 and 100 ppm) and sucrose (1 and 20%) treated plants had similar fresh weights of pods compared to the control (Table 13). NAA (10 and 100 ppm), 2,4-D (10 ppm and 10 ppm with FeEDTA 5 ppm) resulted in increased yields compared to the controls. Only 2,4-D (1 ppm) reduced the yield of beans. The number of blossoms that dropped was similar for all treatments, except NAA (100 ppm) which resulted in increased blossom drop.

In Bush Blue Lake Asgrow #274, IAA (10 ppm) and NAA (10 ppm) had similar fresh weights of pods compared to the control (Table 14). All other treatments reduced the yield of beans. The number of blossoms dropped were similar for all treatments.

In Experiment 13, Bush Blue Lake OSU 949-1964-2 and Asgrow Early Wax produced the highest total and marketable (medium size) number of pods (Table 15). All other varieties had a lower number of pods (total and marketable) with Bush Blue Lake BLS the lowest. Stringless Green

Table 12. Effect of chemical sprays on the fruiting response of Stringless Green Pod bush beans at the University of B.C. in Experiment 12.

Chemical Sprays	Pods Weight (gm.)	Blossoms Dropped (number)
IAA - 10 ppm	1280de	3.0a
- 100 ppm	1377b	3.0a
NAA - 10 ppm	1376b	2.8a
- 100 ppm	1095f	2.6a
Sucrose - 1 %	1320cd	1.6a
- 20 %	1251e	2.6a
2,4-D - 1 ppm	1362bc	2.8a
- 10 ppm	1586a	1.2a
2,4-D - 10 ppm & FeEDTA 5 ppm	1544a	2.6a
Control	1257e	3.8a

Table 13. Effect of chemical sprays on the fruiting response of Tendercrop bush beans at the University of B.C. in Experiment 12.

Chemical Sprays	Pods Weight (gm.)	Blossoms Dropped (number)
IAA - 10 ppm	1032cd	5.6ab
- 100 ppm	1118b	3.8b
NAA - 10 ppm	1208a	4.8ab
- 100 ppm	1196a	7.4a
Sucrose - 1 %	1114bc	2.8b
- 20 %	1089bc	5.4ab
2,4-D - 1 ppm	992d	5.0ab
- 10 ppm	1267a	3.8b
2,4-D - 10 ppm & FeEDTA 5 ppm	1228a	5.2ab
Control	1114bc	3.0b

Table 14. Effect of chemical sprays on the fruiting response of Bush Blue Lake Asgrow #274 bush beans at the University of B.C. in Experiment 12.

Chemical Sprays	Pods Weight (gm.)	Blossoms Dropped (number)
IAA - 10 ppm	2262bc	6.2a
- 100 ppm	2180cd	3.8a
NAA - 10 ppm	2367a	3.4a
- 100 ppm	1837f	2.8a
Sucrose - 1 %	1902f	7.2a
- 20 %	2018e	6.2a
2,4-D - 1 ppm	1879f	3.6a
- 10 ppm	2112d	3.4a
2,4-D - 10 ppm & FeEDTA 5 ppm	2143d	3.8a
Control	2313ab	4.6a

Table 15. Effect of variety on the fruiting response of bush beans in Experiment 13.

		Bush Blue Lake			Stringless	Tendercrop		Asgrow
		OSU 949-1864-2	Asgrow #274	BLS	Green Pod	Bucker-field's	Asgrow	Early Wax
Pods (number)	- Total	624.2a	393.6b	271.0c	336.6bc	358.0bc	389.6b	568.4a
	- Small *	203.8ab	109.4c	86.2c	91.0c	109.2c	141.4bc	251.6a
	- Medium	319.6a	197.6b	115.2c	230.4b	195.8b	179.8b	316.4a
	- Large	100.8a	86.6a	69.6b	15.2c	53.2b	67.6b	0.4c
Pods Weight (gm.)	- Total	3053.0a	2308.0b	1304.0f	1585.0d	1486.0e	1460.0e	1718.0c
	- Small	275.0ab	155.0c	105.0c	115.0c	147.0c	191.0bc	318.0a
	- Medium	1723.0a	1207.0d	556.0f	1333.0c	915.0e	738.0ef	1400.0b
	- Large	952.0a	894.0b	613.0c	136.0f	432.0e	531.0d	3.0g
Pods Percent	- Small	32.5ab	27.7b	31.5ab	27.5b	30.2ab	36.4ab	40.9a
	- Medium	51.2bc	50.1bc	42.5c	67.8a	54.3bc	46.1c	59.0ab
	- Large	16.3b	22.2a	26.0a	4.6c	15.4b	17.5ab	0.2d
Blossoms Dropped (number)		7.8a	2.2c	2.2c	3.2bc	2.2c	5.2b	5.0b
Plants (number)		49.8ab	34.3c	37.4c	56.0a	42.4bc	47.0ab	51.2ab
Pods per Plant		12.6a	9.7bc	7.3de	6.0e	8.4cd	8.3cd	10.9ab

* Small - up to 21/64 inch in diameter at the thickest portion of the pod.

Medium - 21/64-27/64 inch in diameter at the thickest portion of the pod.

Large - 27/64 inches and up in diameter at the thickest portion of the pod.

Pod had a greater percentage of pods in the marketable range than all varieties except Asgrow Early Wax. All other varieties were similar and lower. Bush Blue Lake OSU 949-1864-2 had the highest total weight of pods followed by Bush Blue Lake Asgrow #274, Asgrow Early Wax, Stringless Green Pod, Tendercrop and Bush Blue Lake BLS in order of decreasing yield. Bush Blue Lake OSU 949-1864-2 also had the highest marketable yield of pods followed by Asgrow Early Wax, Stringless Green Pod, Bush Blue Lake Asgrow #274, Tendercrop and Bush Blue Lake BLS. Although differences were shown between varieties, blossom drop was considered to be too low to effect yield.

Stringless Green Pod, Asgrow Early Wax, Bush Blue Lake 949-1864-2 and Tendercrop had a similar number of plants per plot; Bush Blue Lake Asgrow #274 and BLS were lower. Bush Blue Lake OSU 949-1864-2 had a higher number of pods per plant than all varieties except Asgrow Early Wax. The lowest number of pods were Bush Blue Lake BLS and Stringless Green Pod.

In Experiment 14, plants sprayed with IAA (10 ppm), sucrose (1%) and the control had a similar number of pods (Table 16). All other treatments had a lower number of pods with a severe reduction in pod number caused by 2,4-D (10 ppm) and NAA (100 ppm) sprays. Only sucrose (1%) had a fresh weight yield similar to the control. All other treatments had lower pod weight with the higher concentration of the sprays.

In Experiment 15, there were no chemical spray effects on number and weight of pods and the number of blossoms dropped in Tendercrop bush beans at Agassiz (Table 17).

Table 16. Effect of chemical sprays on the fruiting response of Blue Lake FM1 pole beans at Agassiz in Experiment 14.

Chemical Sprays	Pods (number)	Pod Weight (gm.)	Blossoms Dropped (number)
IAA - 10 ppm	726.2abc	3688b	61.8bc
-100 ppm	596.0d	2984d	74.0bc
NAA - 10 ppm	621.8cd	3370c	82.2b
- 100 ppm	241.8f	1442e	204.8a
Sucrose - 1 %	789.4ab	4031a	76.6bc
2,4-D - 1 ppm	709.2bcd	3702b	59.2c
- 10 ppm	482.0e	2918d	69.2bc
Control	828.0a	4200a	82.6b

Table 17. Effect of chemical sprays on the fruiting response of Tendercrop bush beans at Agassiz in Experiment 15.

Chemical Sprays	Pods (number)	Pods Weight (gm.)	Blossoms Dropped (number)
IAA - 10 ppm	227.2a	1674a	7.6a
- 100 ppm	269.6a	1664a	6.4a
NAA - 10 ppm	259.4a	1174a	6.6a
- 100 ppm	231.8a	1732a	9.2a
Sucrose - 1 %	226.2a	1728a	5.6a
2,4-D - 1 ppm	302.0a	1757a	6.8a
- 10 ppm	237.8a	1856a	5.6a
Control	244.8a	1672a	4.6a

DISCUSSION

I. Controlled-Environment Studies.

In all controlled-environment experiments, high day or night temperature decreased leaf weights, while the stem weights at all temperatures were relatively similar. At all temperatures the number of nodes was similar. Height of the plants increased with increasing day temperatures to 90°F but at 95°F the height was reduced. When the day temperature was 95°F, cool night temperatures of 70°F or less resulted in increased plant height compared to the 80°F night. A comparison of number of nodes and total height indicated that at high temperatures the internode length was shorter than at cool temperatures. Plants grown at high temperatures had more axillary branching resulting in similar stem dry weights for all treatments. The decreased height of plants grown at high temperatures might be associated with the destruction of auxin or suppression of auxin formation at high temperatures. This auxin effect has been suggested by Leopold (1955). He reported work with rice seedlings exposed to warm temperatures (26°C or 79°F). These seedlings had a much lower auxin content compared to those exposed to cool temperatures. The shorter stems and greater axillary branching at the higher temperatures could also be associated with low auxin production in the apical meristem.

In experiments conducted in the controlled-environment cabinets, blossoming occurred at all temperature regimes studied. Blossoms on plants growing at 95/80°F and 95/70°F and at 55/40°F temperatures did not set pods. The plants grown at 95/80°F and low 55/40°F temperatures were stunted, and had small dark leaves. The leaves remained dark green for the duration of the experiments, (89 and 133 days for 95/80°F and

55/40°F) although some of the older leaves had dropped. These findings were not in complete agreement with work done by Viglierchio and Went (1957), who work with Kentucky Wonder pole beans. They found that high day and night temperatures (30/24°C or 86/75°F) with an eight-hour day using natural daylight resulted in plants with very long internodes, thin stems and small pale leaves. These plants did not bloom. Plants grown at low day and night temperatures (17/20°C or 62.5/53.5°F and 23/6°C or 73.5/43°F) with an eight-hour day using natural daylight showed stunting, thick stems, short internodes and small dark leaves. The plants eventually yellowed and died without flowering. Comparing Viglierchio and Went's (1957) experiments with present experiments would indicate that there was a daylength or varietal difference in response of bean plants to low and high temperatures.

Many workers (Davis, 1945; Lambeth, 1950; Iwami, 1951; van Schaik and Probst, 1958; Smith and Prior, 1962; Mack and Singh, 1964) have indicated that high temperatures caused blossoms to drop in beans. Lambeth (1950), Watanabe (1953(b)), Inoue and Shibuya (1954) and Ahmadi (1956) showed that failure to set pods at higher temperatures was associated with the inability of the pollen to germinate.

The results of the present experiments agreed with these findings reported in the literature. High day temperatures (90 and 95°F) severely reduced pod set. When the temperature was held at 95°F, plants with the lower night temperatures (60°F) set a few pods, but these pods had only one or two seeds. High night temperatures resulted in 100 percent blossom and immature pod drop. Pod set could take place at lower night temperatures than 70°F since Inoue and Shibuya (1954) found that bean pollen germination was recognizable the afternoon before blossoming, and the percentage germination increased toward the time of blossoming (mainly between 5:00 and 7:00 a.m. (Inoue, 1955)). The temperatures after pollination were more critical than the temperature before pollination (Inoue and Suzuki, 1959). The results of the present experiments on the effect of night temperature were in agreement with studies on lima beans reported by Lambeth (1950) and Rappaport and Carolus (1956).

Although Dale (1964) found that growth under constant conditions was superior to that under alternating conditions, the present experiments showed that the blossoming number, under high day temperature conditions (95°F), was increased as the night temperature was reduced. These findings are in agreement with studies reported by Watanabe (1953(6)).

Plants grown at high day temperatures (95°F) produced pods at all night temperatures, but only at a night temperature of 60°F did any of the pods reach marketable size. Examination of the immature pods showed that none of the ovules had developed. The fruit was therefore parthenocarpic. Johnson and Hall (1954) similarly found that high temperature was associated with parthenocarpy in tomatoes. The immature bean pods in the present experiments did not develop normally and dropped after several weeks. Ahmadi (1956) found that young pods that had dropped were not fertilized and Lambeth (1950) showed that at least one ovule per pod had to be fertilized to start pod development and to prevent abscission. Since the immature, unfertilized pods remain attached to the plant for a long period of time, several weeks must elapse before true pod set can be determined.

There was no relation between the number of blossoms that formed and the number of pods that set, which agreed with studies by Binkley (1932). Even at temperatures low enough to ensure optimum conditions for pollination, not all blossom formed set pods. Pod set at lower temperatures occurred according to the "capacity set" concept first explained by Cordner (1933). Since the plants at 85°F and 75°F day temperatures had a similar plant size, they would be expected to have a similar pod set. The number and fresh and dry weight of pods was similar for plants grown at 85°F and 75°F day temperatures.

Pod set and blossom drop occurred throughout the blossoming period, although the last blossoms formed failed to set fruit. The blossom drop pattern was in agreement with Iwami (1951), Schrader (1943), and Lambeth (1950) who found that once capacity set was attained the percentage of blossoms that set was reduced.

Bush beans were found to have a cyclic pattern of blossoming if the pods were harvested at marketable maturity. The only previous reference to cyclic blossoming in beans was that of Viglierchio and Went (1957) who worked with Kentucky Wonder pole beans.

When pods were harvested at marketable maturity, the plants remained vegetative, and showed renewed growth activity at day temperatures of 85°F or less. The leaf weight increased and the plants remained vigorous. The stem dry weight of plants when beans were harvested at dry maturity two months after planting were 4.57 and 5.53 grams for plants grown at 85° and 75°F respectively. These plants were senescing. When the pods were harvested at marketable maturity the stem dry weights three months after planting were 16.22 and 16.77 grams for plants grown at 85° and 75°F respectively. The height of the plant and the number of nodes were similar for both treatments.

When fertilization occurs, there is a great increase of auxin in the plant (Leopold, 1955). This new supply of auxin moving into the plant stimulates overall plant growth. No conclusions relative to the fruiting effect on plant growth habit could be drawn from plants held at 95/80°F in the present experiments because marketable pods were not produced at this temperature. The longer the plants were held at the high temperature the lower the leaf weight, but the stem weight, total height, and the number of nodes did not change after two months. The fact that there was no increase in growth with time of plants held at 95/80°F with no pod set, would indicate that the lack of auxin supplied by developing embryos resulted in lack of vegetative growth compared to plants that had pods.

From the present experiments it would appear that the cyclic blossoming pattern was related to the capacity set concept of Cordner (1933) at day temperature of 85°F and less. The first cycle, which lasted only 15 days, had the greatest number of blossoms. Even though the first cycle of blossoms was the greatest, subsequent cycles had a higher percentage of pods set. The blossoming cycle of plants grown at 85/70°F was shorter than that of plants grown at 75/60°F. There were fewer days from blossoming to harvest in plants grown at 85/70°F than at 75/60°F.

Plants grown at 85/70°F during a two-month blossoming period produced more blossoms than plants grown at 75/60°F. Pod set and fresh and dry weight of pods was similar. Equal yields between the two temperature regimes supports the capacity set concept, since the plants grown at 85/70°F were no larger than plants grown at 75/60°F.

Blossom drop during the first 15 days of blossoming (first cycle) could follow the theory proposed by Iwami (1951); an early stage of blossom drop, attributed to competition for nutrients between the flowers and the developing plant; a middle stage, attributed to competition for nutrients between flowers; and a late stage, associated with the decline of the plant. Lambeth (1950) found that if capacity set was obtained during the first two weeks after blooming, the yield was dependent primarily on the "active" leaf area and light conditions.

In the second and third cycle of blossoming the plants had fewer blossoms and were more vigorous, and could therefore set a greater percentage of pods.

The high percentage of pod set in the last cycle, especially at 85/70°F, was not indicative of the actual yields. Many of the pods remained small, not reaching marketable size in the time normally required by other pods growing at the same temperature. It could be possible that the natural auxin level in the plant was sufficiently high to prevent the abscission of the young pods, even if they were not fertilized. The extent of fertilization of blossoms was not noted in the present experiments.

Low light intensity caused a reduction in plant growth and number of blossoms. The plants grown at low light intensities had a lower leaf weight than plants grown at high light intensities, and the yield of pods was similarly reduced. Plants grown at low light intensities had a low pod set capacity. These findings were in agreement with studies reported by Inoue and Suzuki (1956).

II. Field Studies.

Plants started at planting dates to May 29, 1964 had similar numbers and weights of pods. Plants started at later planting dates showed reduced numbers and weights of pods. Soil temperatures remained low until the end of May, then increased and remained constant for the remainder of the summer at the University of British Columbia. The June plantings did not have a long enough growing season to produce maximum yields.

The nitrogen level of the soil at the University of British Columbia was sufficiently high for vigorous bean growth because additional nitrogen fertilizer gave no increase in growth. The field had been heavily manured in the fall of 1963.

The row spacing experiments were conducted to determine the effect of air drainage and related humidity as it influenced bean diseases and the effect of plant to plant competition for light and soil nutrients on the number of pods in beans. The two-foot row spacings were too close to allow accurate blossom drop counts. As the row spacing increased, the number and weight of pods per plant increased. When the number and weight of pods were adjusted for area, the narrow row spacings out-yielded the wide row spacings. Comparisons between the eight-foot row spacing and adjacent five-foot row spacing showed similar results for number and yield of pods per foot of row. These results indicated that there was no effective increase in pods set in row spacings greater than five feet. Even though yields per acre were increased at narrow row spacings (11.6, 8.3 and 5.2 ton per acre for two, four and eight-foot row spacings respectively), in commercial fields of pole beans the rows are planted five to six feet apart to increase air drainage and thus decrease the incidence of diseases, and to facilitate havesting.

The row direction experiment was conducted to determine the effect of air drainage and related humidity on the number of pods set and blossoms dropped. Rows planted with the prevailing wind should have better air drainage thus reduce the incidence of *Botrytis* and *Sclerotinia*.

There were no differences in number and weight of pods and blossom dropped between the two row directions. Bean diseases were not a problem at the University of British Columbia in the summer of 1964.

Auxins and sucrose sprays were applied to reduce blossom drop and thus increase yields. Ahmadi (1956) using auxin sprays at blossoming of dry beans found that there was an increase in the number of pods but not in the number of seeds. Auxin applications developed some parthenocarpic fruit. Berrie (1960) found that the supplementary sucrose sprays greatly increased dry weight in tomatoes if conditions for respiration were high and photosynthesis low.

The present experiments showed that unless blossom drop was excessively high, there was no relation between blossom drop and yield, which agrees with findings by Binkley (1932).

In Blue Lake FM1 pole beans none of the sprays increased the yield of beans. Only IAA at 100 ppm, NAA at 10 and 100 ppm and 2,4-D at 10 ppm with or without FeEDTA reduced yields. These findings were in agreement with Murneek, et al., (1944) who found that auxin decreased the yield of pods of plants growing at cool temperatures.

Bush beans were less affected by high concentrations of auxins than pole beans. Only NAA at 100 ppm in Stringless Green Pod bush beans showed a reduction in yield. Increases in bean yields after using auxin and sucrose sprays were noted in Stringless Green Pod and Tendercrop bush beans at the University of British Columbia, but in no case were these increases greater than 13 percent over the control. Murneek, et al., (1944) found that auxin sprays decreased the yield of pods on Stringless Green Pod plants growing at cool temperatures. Temperature records for the summer of 1964 show that the maximum air temperature at the University of British Columbia was 79°F and that only for one day. Controlled-environment studies showed that temperatures of above 85°F were required to cause blossom drop.

Bush Blue Lake OSU 949-1864-2 was the highest yielding bush variety tested. There was not sufficient blossom drop in any variety to show varietal differences. The number of pods per plot was not related to the number of plants per plot. There were varietal differences in the number of pods per plant. High yielding varieties had the greatest number of pods per plant.

Further work on the effect of temperature on growth and fruiting response should include studies on IAA content in the plant, axillary branching, total dry matter production of the plant (including fallen leaves), percentage moisture in the plant, pollen germination, embryo sac development and developing seeds, number of seeds per pod, position of seed in the pod, development of flower primordia, and the effect of constant day/night temperature on pod set (especially 85°F).

Additional work should be conducted to determine the effect of fruiting and harvesting on the cyclic pattern of blossoming in beans, and the effect of cyclic blossoming on the IAA content and CO_2 uptake in the plant, and to determine whether cyclic blossoming is a varietal response.

Additional studies with chemical sprays should include the effect of chemical sprays on the fruiting response when weather conditions are adverse to pod set (in the field and in controlled-environment cabinets), effect of high rates of FeEDTA to reduce growth inhibition caused by 2,4-D at blossoming, and the effect of auxin sprays on the fruiting response when applied to young plants.

There appeared to be a difference in number of pods on the sunny and shady side of the row. Studies should be conducted to determine the effect of row direction on the number of pods on either side of the row.

SUMMARY AND CONCLUSIONS

In controlled-environment studies using Stringless Green Pod bush beans, high temperature was found to be the most critical factor affecting pod set in beans. When day temperatures were high, low night temperature increased blossoming and pod set. As the day or night temperature increased, fresh and dry weights of the leaves decreased. Blossom drop occurred at all temperatures and pod set at temperatures of 85°F and below was considered to occur according to the capacity set concept. Blossoming occurred at all temperature regimes studied.

When pods were harvested at marketable maturity, the blossoming pattern in bush beans was found to be cyclic. Plants grown at 85/70°F day/night temperatures had a shorter cycle than plants grown at 75/60°F. The cyclic blossoming pattern was considered to be associated with the capacity set concept. Plants harvested at marketable maturity were more vigorous and resulted in higher fresh and dry weights of leaves and stems and more blossoms and pods than plants harvested at dry maturity.

Plants grown at a light intensity of 1900 foot-candles had reduced leaf and stem weights, number of blossoms and number and weight of pods compared to plants grown at 2700 and 4000 foot-candles.

Field studies showed that planting dates after May 29 had reduced number and weight of pods in pole beans at the University of B. C. The nitrogen level in the soil at the University of B. C. was high and added increments of nitrogen caused no significant response in the yield of pods in pole beans. As the row spacings increased, up to five feet, the number and weight of pods increased per plant in pole beans. Row direction had little effect on the fruiting response of pole beans.

Use of chemical spays caused no increase in yield of pods in pole beans and only slight increases in yield of pods in bush beans. Of the varieties tested, Bush Blue Lake OSU 949-1864-2 had the highest number and weight of pods. Yield of pods was related to the number of pods per plant.

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