EFFECTS OF NIGHT TEMPERATURE ON THE GROWTH AND DEVELOPMENT OF THE LIMA BEAN

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Lawrence Rappaport

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THESIS

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EFFECTS OF NIGHT TEMPERATURE ON THE GROWTH AND DEVELOPMENT OF THE LIMA BEAN

By

Lawrence Rappaport

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
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Approved Robt. L. Carolus.
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The influences of both pre-bloom and post-bloom night temperatures of 50°, 60° and 70° F. on the growth and development of Henderson Bush lima beans were observed in a greenhouse experiment.

Night temperatures of 50° F. retarded the rate of development prior to blossoming, while 70° F. temperatures accelerated this phase of growth. The date of blossoming was intermediate at the 60° F. temperature. Although the low, 50° F. temperature retarded blossoming by 25 days as compared to blossoming of plants grown at 70° F., after the plants had bloomed, pods on plants grown at the low temperature matured 11 days earlier than those on plants that had been grown to bloom at a 70° F. temperature. Plants grown at the 60° F. temperature tended to be indeterminate in habit of growth, while those grown at 70° F. were even smaller than field-grown plants, indicating an unusual influence of temperature on growth.

Although the number and weight of pods that set were largest at the continuous 50° F. temperature, seed weight was as great on plants grown at 50° F. to blooming and then shifted to 70° F., due to a larger number of seeds per pod. However, the best treatment with respect to seed weight was that in which the plants were grown to the blossom stage at 60° F., and subsequently at 50° F., in which the plants produced pods with the largest number of seeds and seeds of the greatest weight.

In a subsequent experiment plants were shifted at four stages of growth, in all possible combinations of temperatures of 60° and 67° F. This procedure necessitated 16 treatments of each of the two varieties studied and with replication involved 64 pots. The stages at which temperature shifts were employed were: (a) at the complete expansion of the primary leaves; (b) at the development of the second; (c) the fourth; (d) the sixth nodes.

In this experiment the cooler temperature delayed growth up to the fourth and sixth nodes in Fordhook 242, but only to the second node in the Henderson Bush variety. Constant night temperatures of 60° F. resulted in slow growth until the appearance of the sixth node, although plants held at the warmer temperature until the fourth node and then changed to the lower temperature, produced the greatest significant stem elongation. Greatest stem elongation of the Fordhook 242 variety resulted when plants were moved from the warmer to the cooler house at the appearance of the leaves of the second node and held at the cooler temperature until the appearance of the sixth node.

The Henderson Bush variety responded favorably to an alternation of warm and cool temperatures with respect to seed weight and pod weight. In this experiment the plants exhibited the indeterminate type of growth by the time of harvest.

As in the initial experiment blossoming and green maturity were again delayed by cool temperatures as compared with the warmer night temperatures. Generally cool temperature treatments after the appearance of the sixth node resulted in increased seed number, seed weight, and pod number.

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INTRODUCTION

Several plant explorers have confirmed de Candolle's original thesis that the lima bean originated in Central America, probably in what is now Guatamala. Peruvian tombs, the wilds of Mexico, Brazil, Columbia and the inhabited islands of the West Indies have yielded various colored lima beans many of which are now known to be the progenitors of our commercial varieties. From a chance selection in Virginia in Pre-Columbian times the Henderson Bush variety was developed. Thus the slow changes necessary for the dispersion of the lima bean in the Northern climates were manifested in the genetic character of the crop.

The importance of the lima bean has increased considerably and recently the expansion of the frozen food industry has created a large demand for the crop. Statistics (2) for the five year period (1945-1949) show that in almost every state where lima beans are grown for canning and freezing production and acreage have increased materially. One of the problems in growing lima beans is reduced fruit set due to abscission of flowers and fruits. Abscission may occur at anthesis, when the carpel is only partly developed, or later in the season when seeds are in the developmental stage. By far the largest drop takes place in the early stages of flowering and fruit set.

It is known that the percentage of flowers that set fruit varies considerably with both high and low yields occurring in the same location over a period of years. Erratic setting of pods is common under both irrigation and dry land conditions and on sandy and heavy loam soils. High daily temperatures as well as irregular water supply are thought to cause abscission.

In certain areas, particularly along the coastal valleys of California, growers attribute above average crops to the early morning and evening mists which descend over the fields.

It is argued by some that excessive production and abscission are inherent qualities of the lima bean, but occasional high yields suggest the possibility of a physiological unbalance.

Apparently many reasons may be advanced for the excessive abscission of flowers and fruits. A detailed study of various environmental and nutritional factors known to affect the growth and fruiting of plants may eventually yield the secret of setting failure in lima beans.

Because the temperature factor is so essential to the developmental cycle of plants and because the temperature controlled Plant Science Greenhouses at Michigan State College afford facilities for temperature study, this factor was selected for the initial investigation. The problem was resolved in a study of the effects of constant and alternate, cool and warm night temperature periods during selected phases in the life cycle of the lima bean.

REVIEW OF LITERATURE

With the classic work of Sachs (23) the role of temperature as it influences plant growth and development was further clarified. Sachs described periods of optimum, maximum and minimum temperature ranges associated with specific stages of plant growth for particular species. He indicated that a decrease or increase of temperature from the optimum precluded a decrease in plant activity.

In "Thermoperiodicity" (29) Went reviewed the work of several early investigators who detected striking responses to varied temperatures by germinating seeds, dormant buds, and buds initiated in bulbs in storage.

In the same vein Lundegardh (13) quotes Bremer who found that lettuce germination was increased by alternating temperatures. Temperature variations of 6° to 10° F. were found by Thompson and Knott (24) to influence the change from the vegetative to the reproductive state.

Beibel (4) found that high temperatures affect the time of flowering, type of inflorescence and even the response to day length of China Aster.

Studying growth responses of various ornamental plants to temperature Post (18) concluded that definite modifications in plant growth occur as a result of temperature differences.

In a discussion of the reproductive and vegetative states Murneek (17) concluded that certain factors, mainly light and temperature, may cause either continuous vegetative growth or premature bud initiation.

The very conclusive papers by Boswell concerning factors affecting yield and quality of peas further stressed the importance of the temperature factor (6, 7). He found that a rise in temperature during the growing season caused yields to decline. He suggested that a close inverse relationship exists between the time of development to a given stage and the mean temperature for that period. Therefore, the occurrence of a stage, such as blossoming, is dependent on the reception of a constant amount of effective heat, regardless of time. For peas, he concluded, a mean temperature of 68° F. is critical so that a relatively small rise in temperature will reduce yield considerably. A delay in planting (or an increase in effective heat) results in an acceleration of each stage of development including appearance of seedlings above the soil, blossoming stage, and development of seeds and pods.

Growing cosmos at 70° and 55° F. Roberts and Struckmeyer (20) observed that cool, long days inhibited flowering. Soybeans responded in the same manner. With warm, long days the plants grew spindly and developed elongated internodes (21).

The temperature factor is essential not only to the time of bud initiation but to the actual process of fertilization and subsequent fruit development as well.

Cochran (8), studying abscission of greenhouse peppers, compared plants growing at temperatures ranging from 60° - 70° F. to 90° - 100° F. Temperature was found to have a greater effect on the times of anthesis and fruit maturity than any other factor studied. When plants were shifted to the 70° - 80° F. temperature at bloom after being grown at 90° - 100° F., sets increased from 0 to 99.3 per cent. Apparently an optimum temperature range of 70° - 80° F. exists for peppers during the fruit setting period. Interested in the physiological factors affecting blossom drop of tomato, Radspinner found that high temperatures and low humidities favor abscission of tomato blossoms (19).

Binkley (5) concluded that the blossoming period is very sensitive to variations in environmental conditions, inadequate moisture supplies causing decreased fruit sets of snap beans.

Andrews (1) and McGinty and Andrews (15) found that lowered maximum temperatures and high humidities were accompanied by increased yields of lima beans. During conditions of high temperatures and medium to low humidity the blossoms of Fordhook lima beans became dehydrated. Consequently, the enclosed pollen did not germinate while the pistil was receptive, and flower abscission resulted.

In an extensive study of blossom drop of lima beans Cordner (9) wrote that pod yields are closely correlated with bearing area and temperature. As temperature increased fruit setting decreased. He concluded that a great excess of blossoms are produced on the racemes of lima bean plants and that after a "capacity set" is reached abscission occurs as an inherent phenomenon.

Generally, the investigations concerned with factors affecting growth and fruit set have revealed a definite desireability for temperature change during phases of plant growth and development.

Quite recently the researches of Went and his co-workers have been concerned with a temperature factor that influences the plant complex (11, 25, 26, 27). By controlling the night temperature of tomato plants at 18° to 20° C. after the "small plant stage" Went found that increased fruit setting and higher yields were obtained. Night temperature, he found, could be varied with greater effect on plant growth and development than any other environmental or nutritional factor.

Varying the photoperiod and night temperature of 240 species R. H. Roberts (22) showed that warm nights and cool days caused a reduction in setting of Alaska peas and alfalfa while cool nights and warm days increased fruiting.

Quite recently Lambeth (11), concerned with the problem of pod set and yields of lima beans, found that responses to constant air temperatures of 62°, 72°, and

86° F. were a function of variety. At 62° F. the Fordhook 242 variety set 91 per cent of the blossoms while the Fordhook variety set only 37 per cent. In contrast, at a temperature of 72° F. both varieties yielded similarly.

Interestingly, it was found in pollen germination studies that at constant temperatures of 62° F. pollen tube growth and pollen germination was more rapid in the Fordhook 242 variety which had highest sets at the 62° F. temperature than in Fordhook. Lambeth concludes that "these facts provide a possible explanation for the much higher set obtained for the Fordhook 242 variety at 62° F. and may indicate that low night temperatures as well as maximum day temperatures should be considered in pod set".

As did Bailey (3) and Havis (10), Lambeth observed the striking phenomenon of a bush type plant developing indeterminate features. Pod set was apical rather than basal and growth was characterized by elongated internodes which he ascribed to high temperatures and soil fertility, and low light intensities.

An almost linear relationship was found when leaf area was compared to pod yields in the ground bed; however this did not necessarily hold in pot culture.

THE FIRST EXPERIMENT

Methods and Materials

A preliminary experiment was designed to compare groups of plant growing continuously at night temperatures of approximately 50°, 60°, and 70° F. until harvest with plants growing at the above temperatures until the flowering stage when they were moved to one of the other two temperatures until maturity. The work was carried out in various compartments of a greenhouse.

The treatments were replicated three times with one plant per pot. Table I shows the nine temperature treatments comprising the experiment.

Seeds of the Henderson Bush variety were planted on April 26 in 7 inch pots in a mixture of 10 parts of sandy loam soil and 1 part of vermiculite.

Unpublished data by Morris (16) showed that germination of lima beans was reduced considerably at 60° F. and did not occur at 50° F. Therefore, it was necessary to germinate the seeds at 70° F. and to change the pots to the scheduled temperatures when the primary leaves were partly expanded.

Under the conditions of the experiment it was impossible to control day temperature in the greenhouses

TABLE I

ARRANGEMENT OF THE NINE NIGHT TEMPERATURE TREATMENTS COMPRISING THE 1950 EXPERIMENT

Treatment*	Temperature after Germination	Temperature after Blooming
1	50° F.	50° F.
2	50° F.	60° F.
3	50° F.	70° F.
4	60° F.	50° F.
5	60° F.	60° F.
6	60° F.	70° F.
7	70° F.	50° F.
8	70° F.	60° F.
9	70° F.	70° F.

*There were three replications per treatment but it followed that the 50° F. house was generally cooler than either the 60° or 70° F. houses and the 60° F. house was cooler than the 70° F. house.

Data were taken of pod number and weight, seed number and weight, and plant top weight. The plants were considered to be at the bloom stage when five flowers were open.

Results

Temperature Controls. Since the 1950 experiment was preliminary in nature each house was considered as being constantly controlled for the designated temperature. A 70° F. house would indicate that the temperature did not fall below 70° F., however, this was not always possible. In general, the day temperatures in the 70° F. house were warmer than those of the 60° F. and the 60° F. house was warmer than the 50° F. house.

By the first of May control of a 50° F. night temperature was impossible, outdoor temperatures at night being above 50° F.

Effects of Temperature on Flower and Fruit Development. Table II shows the effect of temperature on the number of days to bloom and green maturity.

Delay in days to blossoming in the 50° F. night temperature treatments may be attributed to the inhibition of growth during the cool nights at the start of the experiment. The 60° F. night temperature delayed bloom on an

TABLE II

EFFECT OF NIGHT TEMPERATURE ON THE NUMBER OF DAYS FROM PLANTING TO BLOOM AND TO GREEN MATURITY

Treatment		Number of days: Planting to bloom	Number of days: Bloom to maturity	Total days planting to harvest
1	50*- 50**	62	26	88
2	50 - 60	61	27	88
3	50 - 70	62	26	88
	Average	62	26	88
4	60 - 50	49	38	87
5	60 - 60	48	37	85
6	60 - 70	47	31	78
	Average	48	35	83
7	70 - 50	37	41	78
8	70 - 60	36	40	76
9	70 - 70	39	30	69
	Average	37	37	74

* indicates temperature from the expansion of the primary leaf to the time of bloom

** indicates temperature from the time of bloom to maturity average of 11 days as compared to the plants grown constantly at 70° F. night temperature.

When plants were changed from a 60° to a 70° F. night temperature the period from blossoming to maturity was accelerated. These pods were harvested only two days later than pods from plants held until bloom at 70° F. then shifted to 60° F.

However, the early 50° F. treatments did not follow the pattern. Variation from 50° to 60° or 70° F. after bloom did not accelerate maturity more than constant temperatures of 50° F. A change to 50° F. from either 60° or 70° F. delayed maturity 2 days as compared to constant night temperatures of 60° and 70° F.

Generally plants started at 50° F. were slowest to mature while maturity of plants started at 70° was definitely accelerated by the warmer temperatures.

Effects of Night Temperature on Plant Growth. Night temperatures produced some visibly striking effects on the foliage habit of the normally determinate Henderson Bush Lima Bean. The plants which were grown until bloom at 60° F. developed an indeterminate habit described first by Bailey (3) and later by Havis (10).

Those plants which were placed in the 50° F. house after germination grew slowly and were chlorotic until temperatures during May became warmer. The night temperature in the 50° F. house then became uncontrollable and rapid stem elongation occurred similar to that observed in the 60° F. house.

Contrasted to the elongated appearance of the plants at the 60° F. temperature those plants growing at 70° F. (7, 8, 9) were smaller than field grown plants; the internodes were shorter and the stems were spindly and weak. The 60° F. night temperatures appeared best for plant growth, Table III.

Effect of Night Temperature on Seed Number. The variation in night temperatures caused significant differences in bean seed number, Table III. Treatments 1, 2, 3, and 4 yielded significantly greater numbers of seeds than the other treatments.

Because the first three treatments yielded alike it may be concluded that the change in temperature at bloom did not influence the increase in seed number. At the 50° F. night temperature blooming was delayed favoring increased vegetative growth to that stage. The greater bearing area resulting may have predisposed the plant to a greater fruit set. This reasoning is in keeping with the results obtained by Cordner (9) who found that largest production occurred on plants having the largest bearing areas.

A change from 70° to 60° F. at bloom decreased seed number as compared to constant night temperature of 70° F.,

TABLE III

EFFECTS OF NIGHT TEMPERATURE IN 1950 ON AVERAGE POD WEIGHT, POD NUMBER, SEEDS PER POD, SEED WEIGHT, SEED NUMBER AND FOLIAGE WEIGHT OF HENDERSON BUSH LIMA BEAN PLANTS

	Treatment	Pod weight (grams)	Pod number	Seeds per pod	Seed weight (grams)	Seed number	Foliage weight (grams)
1	50*- 50**	93	31	2.0	37	62	58
2	50 - 60	87	28	2.3	29	63	51
3	50 - 70	73	28	2.4	38	68	42
	Average	84	29	2.2	35	64	50
4	60 - 50	79	26	2.5	44	67	52
5	60 - 60	80	21	2.4	38	50	70
6	60 - 70	92	26	1.6	21	41	71
	Average	83	24	2.2	34	53	64
7	70 - 50	81	20	2.0	27	40	53
8	70 - 60	53	16	1.2	18	19	45
9	70 - 70	53	14	1.8	18	25	50
	Average	62	17	1.7	21	28	49

* indicates temperature from the expansion of the primary leaf to the time of bloom
** indicates temperature from the time of bloom to maturity

while a change to 50° F. at bloom appeared to increase pod set.

Effect of Night Temperature on Seed Weight. Treatments 1, 3, 4, and 5 yielded significantly greater weight of green mature seeds than any of the other treatments; and a change from 60° to 50° F. (Treatment 4) yielded significantly higher than any other treatment.

While no attempt was made to separate or count immature pods, it is suggested that the 60° F. treatment plants produced a greater proportionate weight of mature seeds. This was due to the large number of immature pods observed at the time of harvest on the plants that were grown until bloom at 50° F.

Effect of Temperature on Pod Number, Weight and Number of Seeds per Pod. Pod numbers were greatest on the plants growing from planting to bloom at 50° F. A greater bearing area resulting from the delay in bloom predisposed the plants of the early 50° F. night temperature treatments to a greater fruit set.

Pod numbers were not necessarily related to pod weight. Treatment 3 which yielded a significantly higher pod number, seed number and seed weight did not yield a significantly greater weight of pods. Treatment 5 yielded a significantly high weight of seeds, and a high pod weight, but a decreased number of green mature pods.

The number of seeds per pod was lower in the treatments grown at 70° F. until bloom. The highest average number of seeds per pod appeared on the plants subjected to 50° F. night temperature until bloom or following bloom.

THE SECOND EXPERIMENT

The responses to night temperatures obtained in the preliminary 1950 experiment suggested a more complex study of lima bean plant response to night temperature. The purpose of the second experiment was to determine with higher precision the effects of constant and varied night temperatures during selected morphological stages previous to flowering on the fruiting habit of the lima bean.

Methods and Materials

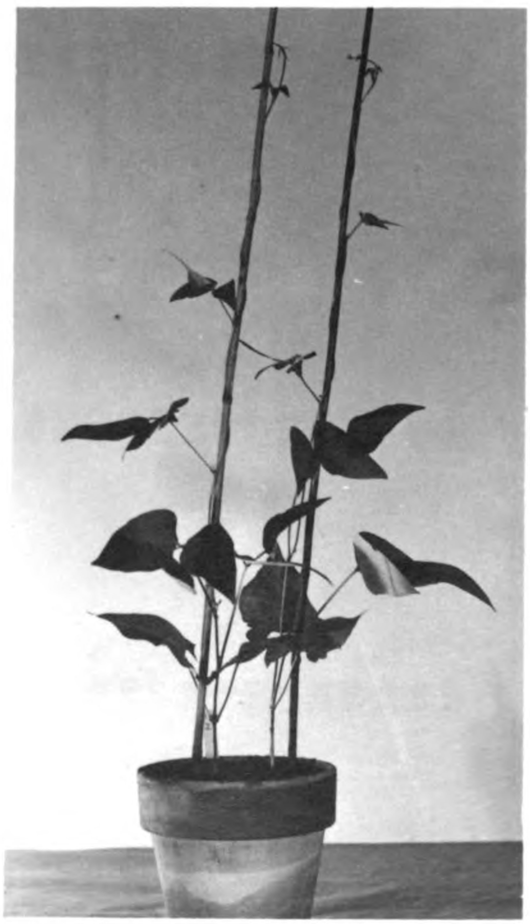
Although significantly higher yields were obtained in the 1950 experiment at 50° F. it was decided to eliminate this temperature from the new series. During late May and until the experiment was concluded in July the outdoor temperature average was higher than 50° F., nearer 60° F. Thermograph readings taken in 1951 tended to substantiate this. Therefore, only 67° and 60° F. night temperatures were employed in a replicated experiment involving two varieties, Henderson Bush and Fordhook 242. Each treatment comprised four temperature changes which were scheduled to occur at specific stages in the development of the lima bean plant. The stages at which the temperatures were changed were: (a) the appearance of the primary leaves in fully expanded condition, (b) the appearance of the second node or the node bearing the first trifoliate leaves, (c) the appearance of the fourth node, and (d) the appearance of the sixth node. The stages at which temperatures were changed are shown in Figure 1 and the arrangement of the experiment is shown in Table IV.

The decision to change treatments at the appearance of a specific node was complicated by variation within a treatment. Not all the plants of a treatment grew to the same stage by the same day; thus a time factor was introduced into the analysis with its accompanying physiological variables. However, it was decided that the need for shifting plants to different temperatures at similar morphological phases was important. This was especially true when it was recognized that the time factor could be reconciled in a reasonable average number of days between changes of replication at each stage. Table V shows the extremes in number of days between a change of replicates of a given treatment at each stage and the average number of days between changes for all treatments of each variety. As in the 1950 experiment, to insure uniform germination and healthy plants the seeds were started in the 67° F. house.

On March 27 seeds were planted hilums down in eight inch pots one inch below the soil surface in a well prepared mixture of two-thirds soil and one-third vermicu-

Second node

Fourth node



Sixth node

Figure 1. Appearance of the treatment plants at

TABLE IV

ARRANGEMENT OF THE 1951 EXPERIMENT SHOWING THE TEMPERATURE CHANGE SCHEDULE FOR SIXTEEN TREATMENTS AFTER ALL PLANTS WERE STARTED IN THE 67° F. HOUSE

Treatment	Primary leaf to second node	Second node to fourth node	Fourth node to sixth node	Sixth node to green maturity
1	60° F.	60° F.	60° F.	60° F.
2	60	60	60	67
3	60	60	67	60
4	60	60	67	67
5	60	67	60	60
6	60	67	60	67
7	60	67	67	60
8	60	67	67	67
9	67	60	60	60
10	67	60	60	67
11	67	60	67	60
12	67	60	67	67
13	67	67	60	60
14	67	67	60	67
15	67	67	67	60
16	67	67	67	67

TABLE V

EXTREMES IN NUMBER OF DAYS BETWEEN A CHANGE OF REPLICATES OF A TREATMENT AND AVERAGE NUMBER OF DAYS BETWEEN CHANGES FOR ALL TREATMENTS OF EACH VARIETY

	Stage		
	Second node	Fourth node	Sixth node
	HENDERSON BUSH		
Extremes in days	3 to 7	5 to 13	3 to 10
Average days for all treatments	4.3	8.0	7.0
	FORDHOOK 242		
Extremes in days	4 to 8	5 to 13	5 to 12
Average days for all treatments	6.25	9.2	6.2

lite. Each replicate was thinned to two plants. When necessary the plants were fed soluble fertilizer having an analysis of 5-25-15 and later 10-52-17.

The observed variations in stem length the previous year suggested a study of the influence of varying night temperatures on stem elongation. The satisfactory use by Went (25) of the elongation of tomato stems as an index of plant growth prompted the use of this criterion of plant growth. Stem lengths were measured in inches at the appearance of the second, fourth, and sixth nodes, and at harvest.

During the course of the experiment the variation in blossom numbers at any given time and between varieties necessitated a count of flowers and pods on all treatments for purposes of comparison. Table VI shows the results of the blossom count taken on May 15.

Other data recorded were days to bloom and harvest, plant weight at harvest, pod and seed weight and pod and seed number.

Statistical Method. A three way classification was employed in the analysis of the data. In the case of the stem elongation data a modification was used wherein a greater number of replicates were made available for the analysis. This can be explained when it is recognized that Treatments 1 to 8 were grown at 60° F. night temperature until the appearance of the second node after being

TABLE VI

A COMPARISON OF THE AVERAGE NUMBER OF BLOOMS ON THE TREATMENT PLANTS OF BOTH VARIETIES ON MAY 15

Treatment		Fordhook	Henderson
1	CCCC	41.	11.2
2	CCCW	14.5	75.5
3	CCWC	63.	94.
4	CCWW	83.	150.5
5	CWCC	22.5	31.
6	CWCW	29.	21.5
7	CWWC	27.	153.
8	CWWW	27.5	26.5
9	WCCC	18.	24.5
10	WCCW	54.	79.5
11	WCWC	19.5	30.5
12	WCWW	17.	33.
13	WWCC	40.5	163.
14	WWCW	54.4	150.
15	WWWC	11.	28.
16	WWWW	28.	115.

C - 60° F.
W - 67° F.

germinated at 67° F. night temperature (Table IV). At the appearance of the second node part of the treatments were shifted to the 60° F. house according to schedule. Similarly, Treatments 9 to 16 were germinated at 67° F. and were permitted to continue at 67° F. until the appearance of the second node. The indicated treatments were then shifted to the 60° F. house. Therefore, in the analysis of stem length for growth to the second node, 16 replicates were used with two varieties and two night temperature treatments: 60° and 67° F. night temperatures. At the fourth node, because of another shift according to schedule, eight replications, two varieties and four treatments were used. The treatments represented changes from 60° to 67° F., 67° to 60° F., and constant 67° F. and 60° F. treatments. With still another change at the sixth node, two varieties, four replicates and eight treatments comprised the analysis.

Results

Until the time of bloom, temperatures were maintained at night in the 67° F. house at 67° F. ± 1°. However, some fluctuation in maximum and minimum temperature occurred. It is difficult to attribute setting differences to night temperatures when it is well known that lima bean fruit setting is also affected detrimentally by high maximum day temperatures.

Control of the 60° F. house was considerably better and it is felt that the results are more reliable. Justification for dependence on the data lies mainly in the excellent control maintained in both the temperature houses until flowering and in the control maintained in the 60° F. house for 12 days after bloom. Too, the variation in temperatures in the 67° F. house after flowering was partially minimized by an average night temperature of 67.5° F. from May 1 to May 25, the period of heaviest fruiting.

Effect of Temperature on Stem Elongation. There were significant differences in stem elongation between varieties. Certain differences were observed in growth at cool and warm temperatures. While the plants started at 60° F. exhibited a deep green color, the leaves were smaller, thicker, and more brittle than those grown at 67° F. night temperature.

Growth to the second node. There were highly significant growth differences between treatments for the Fordhook 242 variety to the second node. Apparently a change in temperature from 67° to 60° F. after the primary leaf stage depressed growth. Quite obviously a high temperature is beneficial for Fordhook 242 in the small plant stage. Henderson Bush variety exhibited a similar trend but treatments were not significantly different.

Growth to the fourth node. The influence of cool temperatures on the early growth increment of the Fordhook 242 variety was expressed more clearly at the appearance of the fourth node. Stem elongation was considerably less when the plants were subjected to a 60° F. night temperature treatment at any time previous to the appearance of the fourth node.

The response of Henderson Bush was quite different from and more difficult to ascertain than that of Fordhook 242 because of the amount of interaction discernable in the statistical analysis. No statistical significance was found when the Henderson Bush variety treatments were analyzed in a randomized block. Figures for both varieties indicate that a constant temperature of 60° F. decreases growth. Data from the fourth node of the Fordhook 242 variety in Table VII show that a change from the warm to the cool temperature at the second node did not cause a growth difference from plants grown constantly at the

TABLE VII

THE INFLUENCE OF NIGHT TEMPERATURE DURING VARIOUS STAGES OF GROWTH ON THE HEIGHT OF LIMA BEAN PLANTS TO THE END OF EACH PERIOD

(Expressed as total height of two plants in inches)

Fordhook 242				Henderson Bush			
First*	Second	Third	Fourth	First	Second	Third	Fourth
12 Cool (60° F)	46C	74C	82C	6 Cool	13C	31C	53C
			85W				62W
		84W	99C			32W	45C
			87W				62W
	45W	82C	89C		17W	25C	50C
			89W				44W
		70W	69C			33W	59C
			79W				46W
17 Warm (67o F)	58C	88C	95C	7 Warm	15C	29C	57C
			88W				45W
		76W	91C			42W	74C
			88W				56W
	57W	76C	96C		15W	28C	53C
			88W				65W
		81W	104C			35W	55C
			102W				59W
L.S.D. (5%)							
4	10	9	10			9	10

*First - to second node; Second - to fourth node; Third - to sixth node; Fourth - to maturity warmer temperature.

Growth to the sixth node. A reversal of trend in growth is discernable in the stem elongation data taken at the appearance of the sixth node for the Fordhook 242 variety. When plants were changed from 67° to 60° F. at the appearance of the fourth node and allowed to continue until the sixth node, greatest stem elongation was recorded. The effect of constant cool night temperature treatment continued to slow stem elongation. However, a change to the warmer temperature after an initial 60° F. treatment was most detrimental to elongation.

When Henderson Bush variety plants were exposed to continuous warm temperatures after the appearance of the primary leaf, followed by a cool temperature period after the fourth node appeared, elongation was most rapid.

Elongation was slowed most by a 67° F. constant temperature treatment after a continuous 60° F. treatment until the appearance of the second node. It is apparent that under the conditions of this experiment the two varieties require different temperature exposures for maximum elongation to the sixth node.

Stem elongation at harvest. A consideration of some importance was the appearance of blossom buds concurrent with the expansion of the leaves of the sixth node. It was thought that the varieties used for this study, being of determinate type, would induce lateral extension as a reaction to bud initiation.

Several investigators have reported the development of an indeterminate habit in lima bean and the stem length results at harvest emphasized this observation. Figure 2 shows the indeterminate type of growth which occurred in all the treatment plants in the second experiment. The final measurements of stem lengths taken at harvest, however, were considerably more than at the sixth node.

When the varieties were analyzed separately in randomized blocks stem length of Henderson Bush plants were significantly different. Greatest significance was found for those plants which were changed from 67° to 60° F. night temperature at the second node, to 67° F. at the fourth node and finally grown to maturity at 60° F. The alternation of temperatures appeared to affect an increase in growth during the reproductive stage. The influence of temperature at various stages is shown in Table VII.

Effect of Temperature on Time of Bloom. The most outstanding effect of temperature on bloom can be observed in the results of the constant cool and warm night temperature treatments (Table VIII). The cooler temperature delayed the time of bloom in the Henderson Bush variety 12 days. Similarly, blooming of the plants of Treatment 1 in the Fordhook 242 variety was delayed 13 days by the 60° F. temperature. Delay in bloom varied from 3 to 12 days in

Figure 2. Typically indeterminate plants of the
Henderson Bush variety

TABLE VIII

INFLUENCE OF TEMPERATURE ON THE AVERAGE DAYS TO BLOOM AND MATURITY OF FORDHOOK 242 AND HENDERSON BUSH LIMA BEANS

Treatment		Average number of days		
		Planting to bloom	Bloom to maturity	Planting to maturity
		FORDHOOK 242		
1	CCCC	43	42	85
2	CCCW	41	37	78
3	CCWC	39	41	80
4	CCWW	36	41	77
5	CWCC	40	40	80
6	CWCW	36	41	77
7	CWWC	35	44	79
8	CWWW	33	36	69
9	WCCC	40	42	82
10	WCCW	35	43	78
11	WCWC	37	37	74
12	WCWW	39	30	69
13	WWCC	37	43	80
14	WWCW	38	30	68
15	WWWC	35	40	75
16	WWWW	30	27	57
		HENDERSON BUSH		
1	CCCC	42	38	80
2	CCCW	38	34	72
3	CCWC	40	35	75
4	CCWW	34	36	70
5	CWCC	41	38	79
6	CWCW	36	36	72
7	CWWC	37	40	77
8	CWWW	35	37	72
9	WCCC	40	38	78
10	WCCW	37	34	71
11	WCWC	38	38	76
12	WCWW	35	34	69
13	WWCC	40	38	78
14	WWCW	33	34	67
15	WWWC	33	40	73
16	WWWW	30	31	61

C - 60° F.
W - 67° F.

the Henderson Bush variety and from 3 to 13 days in Fordhook 242 for all treatments.

Effect of Temperature on the Time from Bloom to Harvest. The same pattern is continued in this stage with warm temperature either accelerating maturity or cool temperature delaying it. The difference between the constant temperature treatments to harvest is in the same order as the number of days to flowering. For the Fordhook 242 variety a constant warm temperature treatment required 27 days for completion of the period from bloom to harvest and the constant cool temperature required 42 days to reach maturity. In the Henderson Bush variety 31 days elapsed at the warm temperature and 38 days after blossoming were required by the cool temperature treatment.

Effect of Temperature on the Time from Planting to Maturity. Here the results are even more striking than in the previous discussion. Fordhook 242 variety required only 57 days to ripen to green maturity at the warmer temperature as compared to 85 days at the cooler temperature. Equally notable was the effect of 67° F. temperature in producing green mature fruit on the Henderson Bush variety in 61 days as compared to 80 days in the constant 60° F. temperature. All treatments other than the constant 67° F. night temperature required 7 to 28 days more to mature for the Fordhook 242 plants and from 6 to 19 days for the Henderson Bush variety.

<u>Effect of Temperature on Seed Number and Seed Weight.</u> The first pod or pods which turned yellow were used as an index of green maturity. At that stage the yield of each plant was harvested. As might be expected the variation in setting pattern and time of set caused some difference in yield. It is assumed, therefore, that seed weight would differ more than seed number and is probably not as reliable an index of maturity. The recent work by Lambeth (11) which states that pollen germination and tube growth was more rapid at constant 62° F. for Fordhook 242 variety than at 72° F. lends impetus to the selection of seed number as the primary index of yield.

As can be seen in Table IX, in the Henderson Bush variety, Treatments 5, 9, and 13 yielded the highest seed number. These treatments were subjected to the 60° F. night temperature after the appearance of the fourth node. In the case of the Fordhook 242 variety, plants in every treatment but Treatment 7, a temperature of 67° F. from the appearance of the sixth node to harvest, yielded as few or fewer seeds than any 60° F. treatment. (Table X). Further, the best treatments for the Fordhook 242 variety were not necessarily the best for the Henderson Bush plants as is shown by the results of Treatment 13. Generally, the cool temperature treatment after the sixth node appears most beneficial to increase in seed number.

Interestingly, the temperature condition most closely approximating normal conditions, that of Treatment 2,

TABLE IX

EFFECT OF TEMPERATURE ON AVERAGE* SEED NUMBER, SEED WEIGHT, POD NUMBER, POD WEIGHT AND PLANT TOP WEIGHT OF HENDERSON BUSH LIMA BEAN

Treatment		Seed number	Seed weight	Pod number	Pod weight	Plant top weight
1	CCCC	67	53	25	106	74
2	CCCW	66	31	31	83	80
3	CCWC	55	42	26	87	61
4	CCWW	41	16	17	51	57
5	CWCC	89	61	33	157	95
6	CWCW	39	18	18	55	44
7	CWWC	69	56	31	122	80
8	CWWW	40	27	19	62	46
9	WCCC	81	61	33	151	85
10	WCCW	29	29	21	75	61
11	WCWC	66	66	36	149	104
12	WCWW	52	35	23	84	63
13	WWCC	75	62	31	130	69
14	WWCW	67	37	23	93	67
15	WWWC	63	42	26	93	61
16	WWWW	48	31	22	82	76
L.S.D. (5%)		11	7	5		

C - 60° F.
W - 67° F.

*Average for two replications

TABLE X

EFFECT OF TEMPERATURE ON AVERAGE* SEED NUMBER, SEED WEIGHT, POD NUMBER, POD WEIGHT AND PLANT TOP WEIGHT OF FORDHOOK 242 LIMA BEAN

Treatment		Seed number	Seed weight	Pod number	Pod weight	Plant top weight
1	CCCC	48.0	86.0	19.5	149.5	84.0
2	CCCW	21.5	45.5	10.0	111.5	21.0
3	CCWC	50.0	82.0	21.0	174.0	127.0
4	CCWW	24.0	51.0	13.0	126.5	155.5
5	CWCC	54.5	92.0	24.5	202.5	166.5
6	CWCW	33.5	70.0	20.5	140.5	138.0
7	CWWC	34.0	60.0	14.0	116.0	63.0
8	CWWW	31.0	58.5	14.5	138.5	101.0
9	WCCC	51.0	85.5	23.5	170.5	124.5
10	WCCW	18.0	48.5	9.5	106.0	122.5
11	WCWC	38.0	68.0	17.0	137.0	77.0
12	WCWW	26.0	39.0	13.0	99.5	59.5
13	WWCC	33.0	62.5	19.0	123.0	91.0
14	WWCW	27.5	47.5	17.5	110.0	78.5
15	WWWC	40.0	69.5	16.0	143.0	96.0
16	WWWW	19.5	32.5	13.0	81.0	94.5
L.S.D. (5%)		11	7	5		

C- 60° F.
W- 67° F.

*Average for two replications

produced only an intermediate yield.

The results of the seed weight analysis of Henderson Bush variety were quite similar to the seed number data. Highest weights were obtained where the night temperature after the sixth node and until harvest was 60° F. The plants which were grown from the appearance of the sixth node at 67° F. yielded the lowest seed weights.

Fordhook 242 variety followed the same trend. Treatments 5 and 9, where temperature was maintained at 60° F. after the appearance of the sixth node, yielded the greatest seed weights. An interesting and indicative result is that of seed weight of Treatment 1, a constant 60° F. night temperature treatment. Seed weight was as high as the consistently high yielding Treatment 9. Treatment 5 in the Fordhook 242 variety was significantly higher for seed weight than any other treatment for both varieties.

Effect of Temperature on Pod Number. The pattern of fruit set tended to follow that of seed weight and number although the differences are not as clearly defined. Again, in Henderson Bush variety, Treatments 5 and 9 did well although Treatment 11 yielded significantly more pods. Treatment 16 was exposed, as were the other high yielding treatments, to a 60° F. night temperature after the appearance of the sixth node.

Likewise, Fordhook 242 variety produced the greatest fruit yields on the 5th and 9th treatments. The same trend found in other 60^{o} F. treatments is apparent in this analysis. The highest yields were found on plants exposed to cooler temperatures after the sixth node.

Effect of Temperature on Pod Weight. It is an interesting fact that pod weight may produce no statistical significance while pod number, seed weight and seed number are highly significant. The trend of increase in pod weight for both varieties was similar to the reported results, cooler temperature affecting increased yields.

Effect of Temperature on Foliage Weight. There was no statistical significance for plant top weight, however certain trends are indicative. Highest yields were not necessarily associated with highest plant weights as shown in Tables IX and X. In the Henderson Bush variety largest plant growth took place under the conditions of Treatment 16 where cool and warm temperatures were alternated at the four stages. Although Treatment 5 in the Fordhook 242 variety produced the largest foliage increase, Treatment 9 was only intermediate in yield.

CONCLUSIONS AND SUMMARY

The fluctuation of night temperature in the warm house during the fruiting period and the high daily maximum temperature may have indirectly caused the increase in productivity obtained for treatments grown to maturity in the cool temperature houses.

The difference in stem elongation observed in the first experiment was not noted in the second.

The first experiment indicated that cool temperatures after germination at 70° F. favored the vegetative phase and delayed blossoming. The resulting increased bearing area at the time of bloom predisposed the plants grown in the cooler treatments to an increase in foliage growth, fruiting, and number and weight of seed.

Plants subjected to 50° F. night temperatures after an initial 70° F. temperature yielded increased weight of seed and a greater number of pods and seeds as compared to those plants growing continuously at night temperatures of 70° F. or those changed from 70° to 60° F.

Shifting plants to 50° F. from either 60° or 70° F. resulted in a greater weight and number of pods and seeds.

The general trend, that of fruit and seed increase at cooler temperatures, is in agreement with the findings of Lambeth (11). He concluded that, differing with variety, pollen germination and pollen tube elongation increased with decreasing temperatures thus promoting more complete fertilization.

In the second experiment a general increase for both varieties in the factors studied was observed in treatments where the plants were exposed after the fourth or sixth nodes to 60° F. night temperature following an initial 67° F. night temperature treatment. However, results for both varieties did not always coincide with treatment. Fordhook 242 variety elongated most at 60° F. temperature after the sixth node. Stem elongation of Henderson Bush variety was greatest when temperatures were alternated.

In both experiments the indication is quite definite that cool temperatures during the reproductive phase are favorable for fruit setting.

In the first experiment warm temperatures accelerated blossoming and delayed maturity, while in the second experiment warm temperatures accelerated both phases of development.

Increased plant top weight did not necessarily indicate large yields probably because of the limited growing environment of a pot. As Lambeth (11) found there was little apparent correlation of productivity and top weight.

A feasible application of this work would be a delay of the blossoming period by the use of high levels of nitrogen nutrition prior to flowering or, possibly, by the use of hormone sprays to delay the reproduction phase thus favoring the vegetative state and an increased bearing area.

The rapid growth manifest in the treatments subjected to the 60° F. temperature after the appearance of the sixth node may indicate a possible increase in nutrient uptake at that stage. A study of nutrient absorption and utilization during the growing cycle of the lima bean may show that an application of a particular nutrient required at the time of bud initiation (sixth node) would affect fruit setting.

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