TB 867 (1944) USDA TECHNICAL BULLETINS UPDATA
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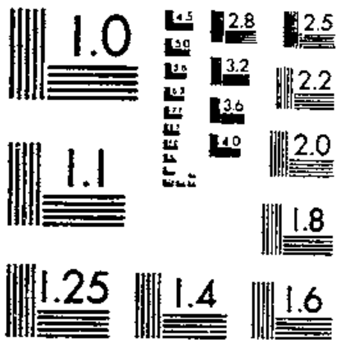

MICROCOPY RESOLUTION TEST CHART
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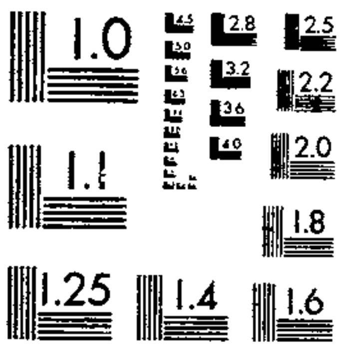

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Technical Bulletin No. 867, April 1944

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

Responses of Beans (Phaseolus) and Other Legumes to Length of Day[1]

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CONTENTS

LENGTH OF DAY AN IMPORTANT CLIMATIC FACTOR

To readers not familar with recent findings of plant scientists who have studied the growth responses of plants, the term "length of day," or "photoperiod," may seem a little strange in relation to legume behavior. For this reason a brief explanation seems appropriate.

The practical grower knows well that temperature, soil moisture, and sunshine are always important factors affecting the growth of his crops. He knows that these are functions of the season and climate of his particular locality, and he realizes fully that he must plant intelligently at the right time and maintain the proper fertility and moisture conditions to obtain the best results.

The grower is less familiar with length of day as a factor greatly affecting plant behavior, because this factor had been almost completely overlooked until comparatively recent years. He knows that light is necessary and that shade and too much cloudiness are detrimental to plant growth. He is well aware that there are marked seasonal changes in the length of day from sunrise to sunset. What he does not realize is the actual effect of the length of day upon growth, flowering, and fruiting.

It is now well established that plants may be most profoundly affected by differences in length of day throughout the seasons and in different latitudes. The days are always short at the equator (table 1), and those of the growing season are always longer at higher latitudes, until continuous daylight prevails at the poles. It would indeed be strange if these great changes in length of day did not somehow affect the expressions of plants.

[1] Submitted for publication Jan. 19, 1943.

TABLE 1.—*Approximate length of day on various dates at different latitudes north of the equator*

Latitude (north)	Dec. 21 (winter solstice)		Mar. 21 (spring equinox)		Apr. 21		May 21		June 21 (summer solstice)		July 21		Aug. 21		Sept. 21 (autumn equinox)	
	Hr.	*Min.*	*Hr.*	*Min.*	*Hr.*	*Min.*	*Hr.*	*Min.*	*Hr.*	*Min.*	*Hr.*	*Min.*	*Hr.*	*Min.*	*Hr.*	*Min.*
0°	12	7	12	7	12	7	12	7	12	7	12	7	12	7	12	7
10°	11	33	12	7	12	24	12	37	12	43	12	38	12	24	12	8
20°	10	56	12	9	12	42	13	9	13	19	13	11	12	43	12	10
25°	10	35	12	10	12	53	13	28	13	42	13	29	12	54	12	10
30°	10	11	12	10	13	4	13	47	14	4	13	48	13	6	12	12
35°	9	48	12	12	13	17	14	9	14	32	14	12	13	18	12	12
40°	9	20	12	12	13	31	14	35	15	2	14	36	13	32	12	13
45°	8	46	12	14	13	48	15	4	15	38	15	6	13	49	12	15
50°	8	4	12	15	14	9	15	41	16	24	15	44	14	9	12	17
55°	7	10	12	17	14	34	16	29	17	21	16	33	14	35	12	19
60°	5	52	12	18	15	8	17	38	18	54	17	41	15	9	12	21

There is another striking thing about length of day and that is its invariable schedules of operation from year to year in different latitudes. Every farmer knows that temperature, sunshine, rainfall, and other climatic factors are very inconstant for any given day from year to year. This is not true of the length of day. It is the only factor of the climatic complex which recurs with almost exactly the same number of hours, minutes, and seconds for the same date from year to year, and this may have happened for thousands or hundreds of thousands of years. This is true because the seasonal length of the day all over the earth is regulated by the revolution of the earth around the sun; it is a fixed astronomical event, a resultant of cosmic mechanics of mathematical accuracy. The sun may deliver more or less energy to the earth from year to year, and thus change the patterns of temperature, moisture, and rainfall from season to season; but the length-of-day schedule is exactly the same year after year.

The latitudinal ranges in length of day are of great significance in determining the successful northward limits of a particular strain or variety of bean in which length of day is a controlling factor. If the plant is a definite short-day type, with a critical limit for flowering near 13 hours, its distribution could extend northward to a latitude somewhere between 25° and 30° N. If the critical length of day for flowering lies near 13½ hours, its limits of distribution would occur near latitude 40°. A critical length of day for flowering near 15 hours would place the northern limits of the plant near 50°. However, at the higher latitudes the mean summer temperatures and the extreme minimum temperatures are lower, imposing additional unfavorable factors limiting successful fruiting before autumn frosts prevail.

It has been shown that some of the tropical or equatorial South American beans (*Phaseolus*) have such rigid requirements for very short days that they cannot flower in summer in the Washington, D. C., area near latitude 39° N. (*2, 7*),[2] when the natural length of day is experienced.

It is obvious, then, that the length-of-day factor is of great importance, and in many respects it is as significant as temperature, rainfall, or soil moisture in the successful growth and fruiting of beans (*Phaseolus*).

[2] Italic numbers in parentheses refer to Literature Cited, p. 23.

LENGTH OF DAY IN RELATION TO THE GROWTH BEHAVIOR OF LEGUMES

The great family of plants known as the pea family (Leguminosae) embraces about 12,000 species distributed among 550 genera. From an economic point of view it stands second only to the grass family (Gramineae). As a matter of fact the former may have an even more varied range of usefulness than the latter or any other family of plants. For this reason, since length of day is often a most important factor in the successful growing of plants, it has been considered timely to give critical attention to the length-of-day responses of some of the more useful legumes, more especially those of the genus *Phaseolus*, which has a world-wide distribution as food for man. About 11 species of *Phaseolus* are cultivated at the present time.

Common field and garden beans appear to have been derived from tropical stock, since they are native to the Tropics and even now may be found wild there. Some of these were introduced into various extra-tropical regions of the world and selections were made on the basis of greater usefulness and adaptation, with the result that now many hundreds of strains and varieties have been named.

The tropical length of day is relatively very short, and the wild stock which existed there was able to adapt its flowering and fruiting to such conditions. Naturally beans which required long days to initiate flowering would have been eliminated by natural selection.

As pointed out in earlier publications (*2*, *7*), some tropical or equatorial South American beans have such rigid short-day requirements that they cannot flower on the natural length of day at Washington, D. C., near latitude 39° N.

Most beans of the species *Phaseolus vulgaris* L. and *P. lunatus* L. are day-neutral; that is, they are able to flower when they experience either short or long days. This particular behavior allows them to be grown over a great range of latitudes, wherever temperatures and other seasonal conditions are suitable. Much of the varietal improvement in beans has been associated with the inherent day-neutral tendency, which is favorable to earliness and extension into either lower latitudes of shortened days or higher latitudes of lengthened days. This is a fortunate relation since otherwise growers would be forced to choose their varieties on the basis of their particular summer length of day, and this would result in much confusion and probably often in many crop failures.

Day-neutral elements occur rather freely in many assemblages of plants which appear to be confined to equatorial subtropical regions, where relatively short days prevail. Beans, tobacco, tomatoes, and many other plants useful in northern latitudes may be mentioned. Both short-day and day-neutral tendencies would persist as genetic characters in the race by natural selection, since these two factors would always allow flowering to occur in low latitudes where short days obtain. Both tendencies, then, would remain as strong latent elements in the genetic constitution of the plants.

In ·· desire to improve his plants and to obtain earlier varieties for more northern regions, man has unintentionally selected and emphasized the day-neutral character, since this would most naturally promote earliness, where the long-day characteristic is practically nonexistent in the assemblage.

In this connection, it is well to emphasize the importance of carry-ing on selection as near as possible to the critical length of day which will initiate flowering, since it is here that the greatest degree of variation in time of flowering will be revealed. This is advisable because all the plants will flower readily in the minimum period of time when subjected to an optimum or very short day, and there will be no opportunities to reveal inherent deviations in relation to a longer critical photoperiod. This principle holds as well for the length-of-day factor as for low temperature where selection is being attempted for resistance to cold or frost.

The beans ordinarily grown in the United States belong to three species: *Phaseolus vulgaris*, including the common field, snap, and kidney beans; *P. lunatus*, including the lima beans; and *P. coccineus* L., including the scarlet runner beans. Of these, *P. coccineus* shows the flowering habit to be favored by long days. This behavior, together with the fact that some varieties of *P. coccineus* are less sensitive to cool summers, explains why they can be grown so successfully in England and continental Europe where cooler summers and very long days prevail at the time of high sun.

Critical study has now been made of some of the most useful types, species, and varieties and strains of beans (*Phaseolus*) when the daily photoperiods were 10, 12, 12½, 13, 13½, 14, 14½, and 18 hours. For comparison plants were grown in each test out of doors at Arlington Experiment Farm, Arlington, Va. (latitude approximately 39° N.), where they were exposed to the naturally changing day lengths. Various other genera (*Canavalia*, *Cicer*, *Lupinus*, *Stizolobium*, *Vicia*, and *Vigna*), of which various species are valuable for feed for stock or soil improvement, were also studied less extensively than *Phaseolus*. The results of the studies are summarized as follows:

Of the *Phaseolus vulgaris* assemblage, 10 of the 20 varieties usually classed as pole beans belonged to the short-day class and 10 to the day-neutral class. In the class known as bush varieties, all of the 24 green-podded and all of the 11 wax-podded varieties tested showed the day-neutral behavior. The flowering of some, for example Red Kidney, was somewhat delayed in response to lengthening photoperiods, indicating a tendency toward the short-day behavior. In the semipole class, 11 were short-day and 8 were day-neutral. Of the 5 Refugee varieties classified as indeterminate in growth habit, 4 were short-day and 1 day-neutral. All the lima beans of the species *P. lunatus* and its variety *macrocarpus* Benth., including 7 bush and 4 pole varieties, were day-neutral in flowering habit. Of the 7 other species of *Phaseolus* tested, 1 strain of *P. mungo* L. showed the short-day and another the day-neutral behavior; 5 other species showed the short-day and 1, *P. coccineus*, the long-day behavior. The species *Canavalia ensiformis* (L.) DC., *Vigna sinensis* (Torner) Savi, and *Stizolobium deeringianum* Bort. behaved as short-day plants. *Cicer arietinum* L. and *Vigna sesquipedalis* (L.) Fruwirth showed the day-neutral behavior and *Lupinus luteus* L. the long-day.

Length of day often determines whether a variety or species is bushy or twining in its growth behavior. The pole varieties of *Phaseolus vulgaris* were twining and the bush varieties were bushy regardless of length of day, but some of the semipole varieties became bushy on the shorter photoperiods and twining on the longer ones. The Refugee varieties, classified as indeterminate in growth form, developed a bushy growth when the days were sufficiently shortened. Most of the lima beans had a rather fixed growth form regardless of the length of the photoperiod, but some of the bush sorts showed tendencies to develop the indeterminate habit of growth as the photoperiods were lengthened.

Phaseolus coccineus showed more vigorous twining on the 10- and 18-hour photoperiods than on any others. The growth form of *P. aconitifolius* Jacq. depended largely upon the day length, and trailing stems developed in response to 18 hours of light. The usually erect and bushy growth of *P. acutifolius* var. *latifolius* G. Freeman was changed to one of recumbent habit when the photoperiods were sufficiently lengthened.

Phaseolus aureus Roxb. was bushy and erect under all photoperiods except the 18-hour, which stimulated a strong twining habit. *P. calcaratus* Roxb. was erect and bushy on the 10- to 13½-hour photoperiods, but developed the twining habit on the other day lengths. *P. angularis* (Willd.) W. F. Wight behaved as a short-day plant. The growth habit of *P. mungo* was not materially influenced by length of day, and that of *Lupinus luteus* was independent of the photoperiod. *Stizolobium deeringianum* was bushy on the short periods and twining on the long ones. *Canavalia ensiformis* completely reversed this behavior, being tall and twining on the short photoperiods and relatively short and bushy on the longer ones. The leaves and pods of the last-named plant were greatly reduced in size as the length of day increased.

It is obvious, then, that the growth form of legumes is a rather variable feature and subject to considerable modification by environmental conditions. A particular growth form expressed by the bush or the twining behavior may be closely dependent upon a particular length of day. This is a point of considerable significance, since some botanists have concluded that many plants have become herbaceous, especially in the Tropics, because they have assumed the climbing habit. Sinnott and Bailey (*18*) expressed this view. The climbing habit, however, may often be brought into expression at will by changing certain environmental conditions, one of which is length of day.

From this brief résumé of the more important behaviors of beans and other legumes as affected by length of day, it is obvious that this is also a very important climatic influence, which the grower too often has failed to recognize in the past.

PREVIOUS PHOTOPERIODIC STUDIES OF LEGUMES

In much of the previous work the soybean has been so extensively used in every phase of study of photoperiodism that it now holds an almost classic position with respect to photoperiodic study. Since the present paper deals mainly with studies of *Phaseolus*, particular emphasis will be given to review of work on that genus in earlier studies.

The earliest mention of the photoperiodic behavior of *Phaseolus* was made in 1920 by Garner and Allard (*7*). Beans (*P. vulgaris*) subjected to the full length of the summer day required 109 days to flower, while those receiving only 7 hours of daylight flowered within 27 to 29 days. Similar responses were shown by several varieties of lima bean (*P. lunatus*) from Peru and Ecuador.

These early and rather limited experiments indicated that some beans are highly sensitive to length of day. In these instances beans required shortened days to flower in northern latitudes and therefore are adapted only to the shorter days of very low or tropical latitudes.

Harvey (*10*) grew *Phaseolus vulgaris* and other plants under continuous artificial illumination during the wintertime and concluded that the plant responses were not due to length of day but to some nutritional modification. It is obvious that his conclusions proved to be somewhat premature.

Garner and Allard (*8*) and Allard and Garner (*3*) showed that *Dolichos biflorus* L. and *Phaseolus multiflorus* Willd. (*P. coccineus*) required short days for flowering, and that root tuberization in *P. multiflorus* was favored by short daylight periods.

In 1923 Lubimenko and Szegloff (*13*) concluded that beans were best adapted to days of short duration, 10 hours being the optimum for full flowering and the production of dry material. They found that the weight of dry substance per unit concentration of chlorophyll increased with decrease in the length of the light periods.

Adams (*1*) noted in his experiments on wax beans that the plants flowered at about the same time in exposed as in darkened plots, but that the plants which had not been darkened produced the greatest weights.

In 1924 and 1925 Tincker's results (*19, 20*) with *Phaseolus multiflorus* were in agreement with earlier results of Garner and Allard (*8*).

In 1929 Doroshenko and Rasumov (*6*) studied the length-of-day behaviors of a number of cultivated plants including *Phaseolus vulgaris* and *P. multiflorus* to determine if any correlation could be found with their geographic origin. The ratio of dry weight of stems and leaves was found to vary greatly, depending upon the length-of-day factor. With 9 hours of daylight, 61 percent of the leaves and 39 percent of the stems of some varieties were dry matter, whereas on the contrary 69 percent of the stem and 31 percent of the leaves of others were dry matter. These workers concluded that a definite relation existed between the country of origin and the photoperiodic response of the beans normally grown there. Southern varieties were naturally adapted to the shorter days of these lower latitudes and showed less delay of flowering in response to the artificially shortened daylight periods. With retarded maturity under short-day conditions an excessive vegetative development occurred, expressing itself in increased yields of dry material and in greater expanse of leaf surface. The latter behavior was also strikingly shown by *Canavalia ensiformis* in the present studies (p. 23).

Maximow (*16*) in 1929 reported the behavior of various economic plants as influenced by different length-of-day treatments. He found that hairy vetch (*Vicia villosa*), chickpea (*Cicer arietinum*), and *Phaseolus multiflorus* responded as long-day plants and *P. vulgaris* as a short-day plant.

In 1933 Heuser (*11*) investigated the effects of successively later plantings upon the behavior of several plants, among which were two varieties of peas (*Pisum sativum*) and a variety of lupine (*Lupinus angustifolius*). The behavior of this lupine led him to conclude that it was a typical short-day plant. He concluded that the earliest sowing for this lupine is not likely to be the ecological optimum for best development, but a somewhat later planting, which in his tests was made about 2 weeks after the early planting. In harmony with the views of Maximow (*16*) it is inferred that very early plantings of short-day plants may prove a serious disadvantage, since they may cause premature flowering before a sufficient amount of assimilative foliage has developed.

Malinowski (*14, 15*) reported the results of length-of-day studies of first-generation plants obtained by crossing two varieties of *Phaseolus vulgaris*. The parent varieties were kidney beans of the bush, or determinate, habit of growth in contrast with the indeterminate habit of growth of the pole varieties. The first-generation plants showed marked hybrid vigor, but flowering was greatly delayed in them. However, when these plants were subjected to 8-hour periods of daylight each day, their stature and growth were reduced to those of the parents, and flowering occurred 6 weeks earlier than in those plants which experienced the full day. The number of internodes, pods, flowers, and seeds produced in response to daylight periods of 8 hours as compared with those for the full day gave the following ratios: Internodes, 6:1; pods, 3:1; flowers, 3:1; seeds, 4:1.

Rudorf (*17*) in 1935 reported the behavior of a number of bean varieties in Germany, comparing the effects of short days of 12 hours with the full summer day of 15 to 16 hours or more in length.

In 1936 Hackbarth (*9*) presented the results of his studies of some lupines subjected to a 12-hour day in comparison with the full day. He concluded that flowering, setting of seed, and fruiting of *Lupinus angustifolius* and *L. luteus* were delayed by a length of day of 12 hours as compared with a full day. However, both species showed so many contradictions of behavior with respect to the length-of-day factor that no definite conclusions could be drawn from their responses. It is thought that both temperature and humidity as well as length of day exercised a strong influence upon the rhythm of development. *L. albus* and *L. mutabilis* showed only slight sensitivity to changes in length of day.

Krassinsky, Kondrashova, and Vinogradova (*12*) in 1936 reported the effects of subjecting plants to a shortened day (12 hours for 20 days from germination) in comparison with plants experiencing the full day to determine what changes occurred in the enzymatic system of beans (*Phaseolus vulgaris*). A shortened day appeared to stimulate a gradual and very considerable increase in the activity of the oxidizing enzymes catalase and peroxidase. Regular changes were also brought about in the hydrolyzing enzymes, amylase and saccharase. These changes were of different degrees in beans as compared with such plants as chrysanthemums. For this reason it was concluded that the inherent characteristics of the species strongly influence the enzymatic relations of the plants in their responses to length of day.

Allard (2) presented the results of a study of the length-of-day behavior of the rather rare wild bean of eastern North America, *Phaseolus polystachyus* (L.) B. S. P. It was shown that this bean flowers most profusely with an intermediate range of day lengths, days that are too short or too long being unfavorable to flowering or even inhibiting it entirely.

A noticeable feature of most of this previous work has been the failure to designate specifically the variety or strain studied in many instances. Often merely the species name *Phaseolus vulgaris* or *P. multiflorus* has been used. This is unfortunate since these species comprise great numbers of horticultural varieties and forms, and it is now known that many of these may show markedly different physiological behaviors, although no clearly discernible differences in morphology may be evident. Under these circumstances it would be impossible to repeat most of this work or to corroborate any conclusions which may have been drawn except in those instances where such conclusions may have wide application as types of general photoperiodic behavior.

MATERIAL AND METHODS

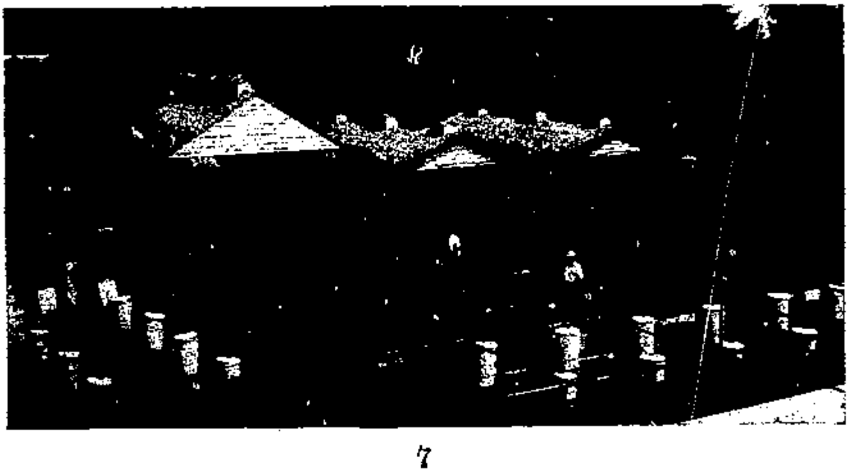
The data obtained for the present paper represent the results of tests carried on at Arlington Experiment Farm, Arlington, Va., near Washington, D. C., from 1939 to 1941. Arlington Experiment Farm is very near latitude 39° N. and experiences a maximum length of day from sunrise to sunset at the summer solstice (June 21) of 14 hours and 54 minutes (14.9 hours).

Different lengths of day were used in the growing of the plants; where practicable the following daily light periods were maintained from germination until maturity of the beans and other legumes: 10, 12, 12½, 13, 13½, 14, 14½, and 18 hours.

For periods of 14½ hours or shorter the natural daylight periods were artificially reduced by the use of large darkened houses (fig. 1) of wood erected upon concrete foundations. These houses were equipped with large ventilators along the entire length of the ridge and a system of openings just above the ground around the base, the construction being such as to intercept all light when the doors were fastened shut during the darkening periods.

The plants were grown in large galvanized-iron buckets of 12- to 14-quart capacity. The seeds were planted out of doors and at germination the seedlings were at once subjected to the various lengths of day. The buckets remained permanently upon movable trucks running in and out of the darkened houses on iron tracks. Definite schedules of darkening were observed daily to maintain constant the various lengths of day from germination until completion of the tests.

FIGURE 1.—Large, ventilated, lightproof houses at Arlington, Va., used for studies of the photoperiodic responses of legumes. In front may be seen containers with the plants resting on movable trucks, which run on iron tracks and carry the plants in and out of the darkened houses on definite schedules.



This equipment made it possible to move the plants readily into darkness or daylight at will. As the temperatures within these lightproof houses varied only 2° or 3° F. from the normal air temperatures at any time, fairly normal conditions obtained for the plants.

As the daily light periods of 18 hours were in excess of the longest summer day of 14 hours and 54 minutes, the use of supplemental artificial light from sunset was required to extend the light periods to this duration. For this purpose four 200-watt gas-filled tungsten lamps with bowl reflectors were arranged at the corners of an iron pipe frame 3 feet square. This rigid metal square was easily moved up and down on iron uprights, so that the four lights could be readily adjusted simultaneously and maintained at a distance of about 1 foot above the plants. The intensity of light falling upon the plants at a distance of 1 foot was measured by a Weston illumination meter, Model No. 1746. This was equipped with a Viscor filter to obtain only visible radiation as nearly as possible and gave a reading of about 300 to 400 foot-candles.

The seasonal changes in length of day and the temperature requirements of the plants made late planting necessary in order to begin the tests for the longer as well as for the shorter daylight periods at the same time. For this reason plantings each year were begun on May 23 or 24, since on May 23 the days from sunrise to sunset are 14½ hours long. It should be stated that the longer daylight periods which the test plants experienced must terminate as soon as the natural daylight interval has fallen to these lengths, and after this termination the plants must be subjected to the normal progressively shortening days if natural daylight alone is used. The 10-hour day in the Washington, D. C., area begins January 25 and continues above this length until November 17; the day is at least 12 hours long between March 18 and September 27; 12½ hours between March 29 and September 15; 13 hours between April 11 and September 3; 13½ hours between April 23 and August 21; 14 hours between May 6 and August 7; 14½ hours between May 23 and July 22. Flowering on some of the longer lengths of day may have been delayed until after the period of seasonal shortening had begun. If this occurred, however, it is obvious that the particular length of day concerned was too long to hasten flowering as did some shorter day lengths.

The effects of the natural increments and decrements in length of day of the warm season before and after the summer solstice on the behavior of plants are very difficult to evaluate. While the full day prevailing during the period of the tests has usually been selected as a control, it is recognized that this is not an entirely satisfactory one in some respects, since it represents a constantly moving length of day throughout the season, increasing before June 21 and decreasing at the same rate thereafter. While some workers have expressed this in terms of an average length of day for a given period, this represents a loose and even inaccurate limitation for certain plants, since in some instances flowering is initiated by a very high critical length of day, which may exceed an average value computed from minimum and maximum values.

A constant length of day using natural daylight and equal to the shortest durations of the tests would perhaps serve as the most satisfactory control. A daylight period of 12 hours is perhaps as satisfactory as any other for this purpose, since it is hardly practicable anywhere in northern latitudes to grow plants much before April 1, when this or a somewhat longer day obtains. However, as the full day represents the natural seasonal condition for growth out of doors, this is designated as the control series as in the past.

To facilitate free drainage at all times, several large holes were punched in the bottom of the galvanized-iron bucket containing the plants, and over this a layer of cinders was spread to a depth of about 1 inch. The soil consisted of an artificial mixture of good river sand and clay together with a good proportion of well-decayed leafmold added to make a porous sandy loam. At regular intervals throughout the growing season the plants were fertilized with liberal applications of manure water equally applied to all buckets, so that the plants made excellent growth throughout the tests. Insect pests were controlled without spraying, which sometimes injures the foliage.

Three plants equally spaced around the periphery were grown in each bucket. Height, growth habit, number of pods, and other significant data were obtained. Measurements of plant height were made at flowering or, if flowering did not occur, at the ends of the tests. In practically every instance a perfect stand of plants and vigorous growth obtained throughout the tests.

The present study was concerned mainly with commercial varieties of beans of the genus *Phaseolus* grown in the United States, practically all of which are included in the species *P. vulgaris*, *P. lunatus*, and *P. coccineus*. In addition several other annual species of *Phaseolus* and several other legumes were studied.

Although some varieties of *Phaseolus vulgaris* normally show a certain growth form rather persistently in response to all photoperiods, other varieties display great modifications of this, depending upon variations in light intensity, temperature, humidity, and length of the photoperiod (table 2).

A number of the varieties usually classified as pole beans are strictly day-neutral; among these are Ideal Market, Kentucky Wonder Morse 191 (fig. 2, *C*), Kentucky Wonder Wax No. 765, and McCaslan. Others, including London Horticultural, Cutshort, White Cornfield, Logan Giant, Blue Lake, and Golden Cluster Wax, showed a more or less marked delay in time of flowering in response to the longer photoperiods, thus showing short-day tendencies. This delay in flowering as the day becomes longer may within limits increase the value of a variety in high latitudes, so long as it is able to mature a crop before frost. The long vegetative period permits the development of a larger bearing area and possibly greater yield per plant than if relatively heavy bearing occurred very early.

Many varietal characteristics and adaptabilities to climate must be taken into consideration before conclusions can be drawn as to regional adaptation on the basis of day-length behavior. Many varieties here found to be short-day plants are admirably suited to the northern United States.

London Horticultural showed a gradual and consistent delay in flowering as the photoperiods exceeded 13½ hours. While flowering occurred in 24 to 26 days in response to the shorter photoperiods, the period increased to 33 days for the 14½-hour photoperiod, to 65 to 70 days for the full-day, and to more than 109 days for the 18-hour photoperiod. The plants on the last photoperiod had not budded when the tests were discontinued in late September. Among the tested varieties usually classified as semipole, South America No. 1, French Horticultural, Goddard, St. Louis Perfection, and White Half Runner are garden types; Great Northern U. I. No. 81, Large White Marrow, Michelite, Otenashi, Pink, the two Pinto strains, the Red Mexican strains, and Robust are field, or dry shell, varieties. The Brazilian varieties tested are not known enough to classify precisely, but they appear to be semipole.

Although a number of these semipole varieties are day-neutral, the majority, especially the field sorts, show a more or less pronounced short-day behavior. In some instances this is indicated by a rather slight retardation of flowering in response to the longer days, as in the case of Michelite. Others, such as Large White Marrow, Pink, and Pinto (Colorado strain), show a great delay in time of flowering in response to the longer photoperiods. Pink (fig. 2, *B*) is outstanding in its short-day behavior, flowering being delayed 114 days in response to the 18-hour photoperiod and the determinate bush-growth form being developed in response to the shorter lengths of day. This variety did not assume the twining habit of growth until a 14-hour photoperiod had been experienced.

The Red Mexican strains also showed the dwarf-bush habit of growth on the shorter photoperiods, but tended to become twiners on the longer photoperiods.

The varieties Pink and Pinto (Colorado strain) do not appear to be adapted to high latitudes, where both the longer days and cool temperatures would operate to cause delayed flowering. The Idaho strain of Pinto showed a behavior very similar to the Colorado strain on all photoperiods except the full-day and the 18-hour, when pronounced differences in the two strains were shown. The responses of the former indicate that it may be better adapted to higher latitudes than the latter.

Certain green-podded Refugee varieties of garden beans are characterized by an indeterminate habit of growth. This type of plant in its typical form is characterized by weak, elongate branches tending to become twining in habit. Under the conditions of some of the tests this behavior was nearly suppressed except on the longer photoperiods.

In 1888 the Early Refugee, introduced by J. M. Thorburn & Co., came into prominence and proved to be much superior to the older sorts because of its bush habit of growth, earliness, productiveness, and fair table quality. This variety has shown a strictly day-neutral response to length of day, and this has doubtless contributed to its ready adaptability to a wide range of conditions in northern latitudes where long summer days prevail.

The Idaho Refugee and the Stringless Green Refugee also adapted to the North have shown rather pronounced short-day behaviors, reacting with considerable retardation in flowering in response to the longer photoperiods. U. S. No. 5 Refugee has shown a somewhat less pronounced short-day behavior.

The shorter lengths of day stimulated these varieties to develop the more typical bush form, rather than the indeterminate behavior.

Twenty-four varieties of green-podded bush beans, of which only the varieties

TABLE 2.—*Responses of certain varieties of Phaseolus vulgaris to length of day*

Kind and variety	Year tested	Effect of daily exposure of—																		Length-of-day class
		10 hours		12 hours		12½ hours		13 hours		13½ hours		14 hours		14½ hours		Full day [1]		18 hours		
		Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	
		Days	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	
Green-podded pole:																				
Alabama No. 1	1941	33	30	33	23	31	38	33	30	34	31	47	21	47	41	40 47	23 18	44	39	Short-day.
Blue Lake	1940	32	43	30	40	32	46	32	52	41	76	42	72	45	75	49 49	60 75	48	53	Do.
Cutshort	1940	31	19	34	32	28	27	30	33	41	7	31	46	43	28	40 40	31 35	99	82	Do.
Dutch Caseknife	1940	40	20	72	64	37	56	46	62	48	38	44	48	(2)	----	46 46	39 44	48	53	Day-neutral.
Ideal Market	1940	31	40	30	30	30	54	30	43	30	47	30	43	30	38	31 31	13 16	32	25	Do
Kentucky Wonder White Improved (Burger Stringless).	1940	42	21	35	13	42	23	40	25	49	36	42	33	47	38	40 40	20 28	49	35	Do.
Kentucky Wonder No. 780	1939	28	34	28	34	42	28	32	45	37	48	45	72	44	55	53 56	40 42	42	40	Short-day.
Kentucky Wonder U. S. No. 3.	1939	28	46	28	42	29	38	29	46	28	48	43	36	37	70	43 42	23 34	39	33	Do.
Kentucky Wonder Morse 191.	1940	32	70	34	73	34	72	39	60	34	84	40	72	36	78	37 37	37 40	37	48	Day-neutral.
Logan Giant	1941	29	30	29	33	28	27	30	34	30	24	31	40	33	50	54 54	30 25	79	47	Short-day.
London Horticultural	1939	24	35	24	26	26	32	26	22	26	32	29	38	33	51	65 70	58½ 56	(3)	(4)	Do.
McCaslan	1940	40	16	36	53	37	57	44	60	39	72	36	63	40	72	39 39	43 31	48	80	Day-neutral.
Missouri Wonder	1940	49	27	44	15	48	18	55	23	34	37	67	42	39	20	40 40	19 22	48	46	Do.
Oregon Giant	1941	27	48	28	50	31	48	29	50	26	34	31	50	31	50	33 33	25 20	35	39	Do.
Striped Creaseback (Scotia)	1939	30	64	28	48	37	60	30	41	34	68	41	68	43	93½	44 45	49 60	41	42	Short-day.
Tennessee Wonder	1940	28	37	30	41	30	48	30	38	28	45	32	37	30	82	36 36	30 34	38	40	Day-neutral.
Do	1941	27	33	27	33	29	30	26	30	28	33	30	34	29	37	33 33	24 24	33	22	Do.

White Cornfield	1941	28	26	28	14	28	27	28	21	30	33	31	40	51	55	83 83	56 56	104	56	Short-day.
Wax-podded pole:																				
Golden Cluster Wax	1940	35	34	24	31	28	33	27	32	30	37	36	54	42	60	56	64	98	69	Do.
Kentucky Wonder Wax No. 765	1939	28	46	29	41	28	48	26	59	29	48	28	58	28	60	31 31	42 46	31	44	Day-neutral
Kentucky Wonder Wax	1939	30	68	37	60	37	70	30	66	37	82	33	81	37	76	42 42	45 48	39	46	Do.
Green-podded semipole:																				
South America No. 1	1941	27	23	26	14	26	29	26	35	26	27½	28	24	30	38	30 31	16 15	25	34	Do.
Brazil:																				
P. I.[3] 140057	1941	31	17	34	26	29	25	33	28	34	22	34	21	33	22	34 38	12 13	40	19	Do.
P. I. 140058	1941	38	10	36	19	33	18	33	20	34	16	33	16	36	17	36 36	13 9	35	16	Do.
P. I. 140059	1941	26	9	26	12	26	13	28	11	28	10	31	12	31	13	39 34	9 11	34	16	Do.
P. I. 140060	1941	44	6	40	11	36	14	36	15	36	8	33	13	38	12	40 36	11 14	35	16	Do.
French Horticultural	1939	28	32	28	33	26	26	28	32	26	29	28	34	29	32	31 29	23 21	39	34	Do.
Goddard	1940	21	7½	20	12	23	11	23	14	23	11½	23	11	27	9	28 28	10 11	31	10	Do.
Great Northern U. I. No. 81	1939	24	16	23	23	24	20	25	19	25	16	24	24	28	25	31 31	21 19	39	30	Short-day.
Large White Marrow	1940	32	24	42	27	35	28	32	40	46	41	36	65	33	57	39 39	31 45	57	44	Do.
Michelite	1941	34	14	33	18	33	22	33	31	36	20	34	22	31	21	43 47	10 13	43	20	Do.
Do.	1941	33	22	31	13	31	25	33	16	33	29	33	24	33	22	34 34	16 16	38	31	Do.
Do.	1940	34	18	34	28	34	27	32	18	32	32	37	39	39	34	39 39	27 32	[illegible]	32	Do.
Otenashi	1940	27	15	23	20	28	15	27	18	25	11	26	15	31	20	34 34	15 19	32	22	Do.
Pink	1940	21	4½	24	5	23	4½	23	6	34	19	49	10	51	20	76 76	50 50	114	62	Do.
Pinto (Colorado strain)	1939	23	13½	23	20	24	23	23	20	23	24½	29	37	29	33	42 44	40 37	99	56	Do.
Pinto (Idaho strain)	1939	24	21	30	39	23	19½	29	26	25	20½	26	30	30	30	30 33	25 15	39	37	Do.
Red Mexican U. I. No. 34	1941	31	24	31	22	28	15	33	20	30	16	31	19	33	30	34 34	11 11	47	30	Do.
Do.	1941	30	17	30	19	31	33	33	22	33	25	33	25	36	28	43 36	16 14	52	18	Do.
Red Mexican	1940	32	6	38	11	31	16½	30	8	36	16	39	12	40	19	42 42	15 16	39	22	Do.
Robust	1939	28	26	29	31	29	30	29	32	32	35	37	56	37	43	41 41	35 20	37	24	Do.
St. Louis Perfection	1941	39	28	38	40	33	50	36	50	34	50	33	50	47	21	47 47	20 13	47	34	Do.
White Half Runner	1941	36	17	36	23	38	20	33	16	31	14	36	28	31	23	36 36	15 10	33	23	Day-neutral

See footnotes at end of table.

TABLE 2.—*Responses of certain varieties of Phaseolus vulgaris to length of day*—Continued

Kind and variety	Year tested	Effect of daily exposure of— 10 hours: Time required to flower	10 hours: Height	12 hours: Time required to flower	12 hours: Height	12½ hours: Time required to flower	12½ hours: Height	13 hours: Time required to flower	13 hours: Height	13½ hours: Time required to flower	13½ hours: Height	14 hours: Time required to flower	14 hours: Height	14½ hours: Time required to flower	14½ hours: Height	Full day[1]: Time required to flower	Full day[1]: Height	18 hours: Time required to flower	18 hours: Height	Length-of-day class
		Days	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	*Days*	*In.*	
Green-podded indeterminate:																				
Corbett Refugee	1940	30	9	30	13	30	15	32	18	36	20	37	19	(2)	------	39 39	17 18	(2)	------	Short-day.
Early Refugee	1939	23	9	23	11	24	11	23	11	24	12	23	10	26	11½	26 28	8 9	26	9	Day-neutral
Idaho Refugee	1939	28	12	26	9	28	11	26	13	29	18	37	22½	37	26	39 42	25 16	50	23	Short-day.
Stringless Green Refugee	1939	24	10	24	10	37	10	29	15	28	13	37	12½	37	22	42 42	18 18	63	15	Do.
U. S. No. 5 Refugee	1939	28	11	26	14½	28	13	26	13	28	18	31	23½	37	27	37 37	19 22½	42	36	Do.
Green-podded bush:																				
Asgrow Stringless Green Pod	1939	23	13½	22	14	24	17	24	18	23	18½	22	18	21	20	28 28	13 11	24	22	Day-neutral
Asgrow Black Valentine	1939	24	19	22	17	24	18	23	20½	23	20	23	22½	25	15	28 28	13 13	26	19	Do.
Boston Yellow Eye	1940	30	16	30	17	30	19	30	14	32	15	30	26	32	23	32 32	15 15	30	23	Do.
Do	1941	31	14	30	41	31	17	32	13	34	26	30	23	33	26	33 33	17 15	33	20	Do.
Black-Seeded Green Pod	1940	20	8½	23	12	23	12	23	10½	23	12½	23	10½	23	10½	25 25	14 12½	23	11	Do.
Bountiful	1939	23	10½	22	20½	23	13½	23	18	22	16	22	16	23	15	26 26	13 14	29	15	Do.[6]
Burpee Stringless Green Pod	1939	25	15½	22	21	23	17	22	18½	23	21	23	19	22	15	29 29	16 14	28	15	Do.
Canadian Wonder	1940	25	8	25	10	30	12	30	11	32	14	34	12	34	13½	38 38	14 12	31	11	Do.[6]
Commodore	1940	25	8	23	7½	24	7	24	8½	24	8	23	8½	24	6½	24 24	9 10	24	9	Do.
Cranberry	1940	26	23	26	24	27	26	30	26	28	31	30	32	32	33	34 34	23 20	36	30	Do.
Dwarf Horticultural	1939	22	19	24	16	25	15	25	18½	23	22	23	20	23	19	25 26	12½ 12	24	18	Do.
Early Mohawk	1940	23	10½	24	12	24	11	21	11	23	13	23	10	26	7	27 25	13 13	24	12½	Do.
Fordhook Favorite	1940	23	9	23	11	24	10	26	12½	26	14	24	9½	24	7	25 28	10 13	24	10	Do.

Full Measure	1939	23	14	24	17	25	17½	23	19	26	23½	24	18½	26	21½	29 32	16 16	26	20	Do.
Giant Stringless Green Pod	1939	22	10½	23	14	25	13	25	16	22	15	23	15	23	15	25 28	10½ 11	25	17	Do.
Konserva	1941	24	9	24	13	24	12	23	13½	23	9	24	10	24	9	27 27	10 8½	26	16	Do.
Landreth Stringless Green Pod	1939	23	15	23	16	26	16½	25	14	23	16	24	15	25	20	28 28	15 15	26	22½	Do.
Longfellow	1940	27	9	23	13	25	12	24	12½	24	12	25	14	25	13	27 27	14 14	26	13	Do.
Low Champion	1939	23	13	23	14½	23	13½	25	17½	28	16½	29	21½	28	16	31 31	9 13	31	21	Do.[6]
Masterpiece	1940	25	8	25	7	26	8	25	7½	24	9	23	11	26	9	25 26	11 11	27	11	Do.
Do	1941	27	6½	26	10	26	12	26	12½	28	12	27	11	26	15	20 29	10 10	28	16	Do.
Plentiful	1940	23	10	24	26½	24	13	27	16	26	20	26	12	25	19½	31 31	18 14	27	15	Do.
Red Kidney	1939	23	15½	23	20	25	18	26	23½	28	20	29	22½	40	30	33 33	22½ 19	37	21	Do.[6]
Red Valentine Stringless	1939	24	11	24	11	24	13	22	12	24	11	24	13	24	13	28 28	11 11	28	12	Do.
Tendergreen	1939	22	13½	22	14½	25	22½	23	17½	26	17	26	13½	22	18	37 28	13 13	31	15	Do.[6]
Tennessee Green Pod	1940	23	8	23	7	26	7	23	8	23	10	24	11½	26	7½	28 28	11 16	30	12	Do.[6]
Wax-podded bush:																				
Brittle Wax (Round Pod Kidney Wax).	1941	24	10	23	15	24	16	23	11	24	14	24	15	24	15	26 26	9 12	26	17	Do.
Do	1939	23	15½	28	14	26	15	26	17½	26	22	26	21	28	18	28	15	26	18	Do.
Currie Rust Proof Wax	1941	26	23	24	14	24	15	24	13	24	14	26	12	26	15	27 27	13 9	26	20	Do.
Davis Stringless Wax	1940	26	9	28	11	28	12	26	12	30	14	28	10	25	9½	30 30	12 11	26	11	Do.
Dwarf Black Wax	1940	27	11	26	12	24	12	23	10	25	11	26	12	28	11	26 26	14 11	27	12	Do.
Hardy Wax	1940	38	14	41	12	40	14	44	15	47	18	42	17	46	13	42 42	12 12	40	14	Do.
Hodson Wax	1940	30	9	34	15	31	14	34	16	37	17	37	20	37	18	39 39	17 16	48	21	Do.[6]
Improved Golden Wax	1940	25	7½	25	8	24	8	30	14	26	8	26	12	28	12	25 25	11 12	30	16	Do.
Improved Stringless Kidney Wax	1939	28	12½	23	16	26	16	26	17	28	19	24	20	25	15½	28 28	13 12	37	19½	Do.[6]
Pencil Pod Black Wax	1939	24	13	25	15	24	16½	25	14½	26	19	25	18	26	17	29 29	13 12½	26	16	Do.
New Sioux Stringless Wax	1940	25	8	25	9	24	8	24	8	23	9½	27	10	24	10½	25 25	14 13	26	11	Do.
Sure Crop Wax	1940	25	10	25	9	25	10	23	12	23	12	24	12½	24	9	28 27	13½ 16	24	16	Do.

[1] When the full day was represented by 2 controls, the values for both are given.
[2] No germination.
[3] Not in bud Sept. 15.
[4] Not in bud when the tests were discontinued in late September.
[5] P. I. refers to the accession numbers of the Division of Plant Exploration and Introduction.
[6] Some delay in flowering as the photoperiods increased may indicate short-day tendencies. Classed provisionally as day-neutral.

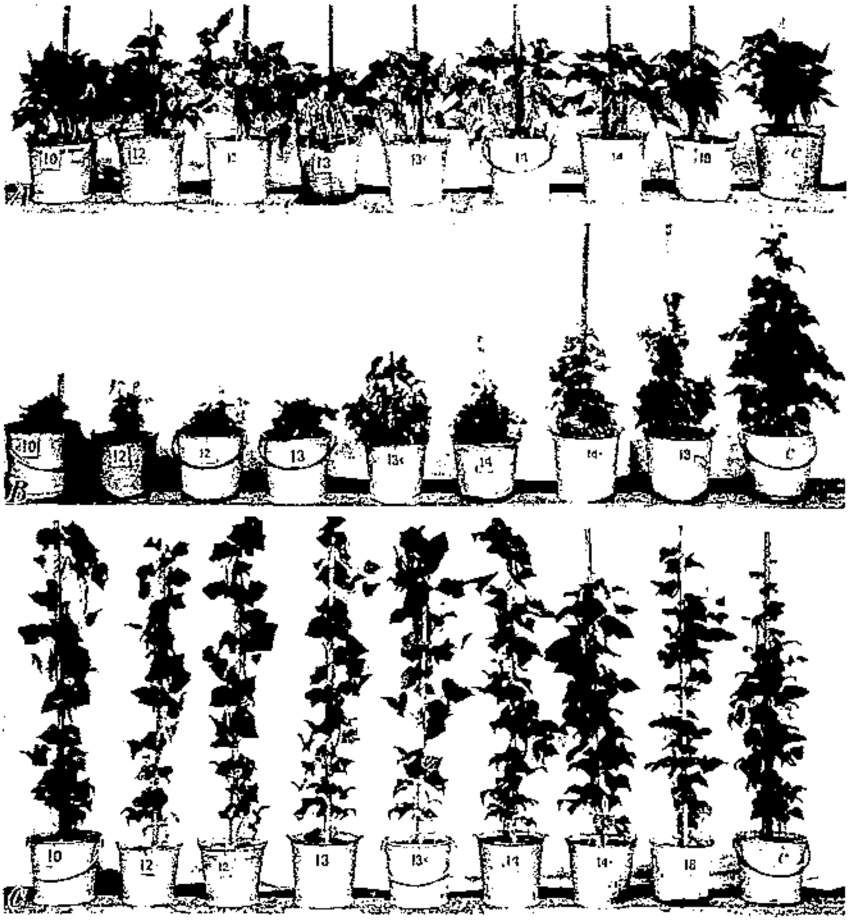


FIGURE 2.—Various green-podded snap beans after being subjected from June 1 to July 25 to the hours of daylight shown on the buckets. *A*, Masterpiece, a strictly day-neutral bush variety. The plants flowered as follows: 10- and 12-hour, 25 days; 12½-hour, 26 days; 13-hour, 25 days; 13½-hour, 24 days; 14-hour, 23 days; 14½-hour, 26 days; full-day (*c*), 25 and 26 days (2 controls); 18-hour, 27 days. *B*, Pink, a decidedly short-day twining field variety. The plants flowered as follows: 10-hour, 21 days; 12-hour, 24 days; 12½- and 13-hour, 23 days; 13½-hour, 34 days; 14-hour, 49 days; 14½-hour, 51 days; full-day (*c*), 76 days; 18-hour, 114 days. Note the great delay in time of flowering and the high twining growth on the longer days. *C*, Kentucky Wonder Morse 191, a day-neutral pole variety. The plants flowered as follows: 10-hour, 32 days; 12- and 12½-hour, 34 days; 13-hour, 30 days; 13½-hour, 34 days; 14-hour, 40 days; 14½-hour, 36 days; full-day (c) and 18-hour, 37 days. Note that plants subjected to the shorter days were taller.

Boston Yellow Eye and Masterpiece (fig. 2, *A*) were grown for more than one season, were tested. All are classified as garden types except the varieties Boston Yellow Eye and Red Kidney, which are field beans. All with the exception of Boston Yellow Eye and Cranberry, which showed a somewhat viny growth, developed the determinate bush growth form in response to every photoperiod, whether this was short or long. These beans showed no significant differences of response to extreme changes in the length of the photoperiod and, therefore, behaved as strictly day-neutral plants in these tests.

Several varieties, including Bountiful, Canadian Wonder, Low Champion, Red Kidney, Red Valentine Stringless, Tendergreen, and Tennessee Green Pod, have shown a rather consistent but slight delay in flowering in response to the longer photoperiods. This behavior, beginning with the 14½-hour photoperiod, is particularly marked in the case of the Red Kidney bean. Some of these varieties showed the most pronounced changes in this direction in response to the full-day and the 18-hour photoperiods. These relations indicate that these varieties may be actually short-day plants, since flowering and fruiting tend to become delayed on the longer photoperiods. This question could be more definitely settled if beans were subjected to much longer lengths of day, including continuous sunlight, and if at the same time optimum warm temperatures, which the bean plant requires for its best growth, were maintained.

Since this question cannot be entirely settled at the present time, owing to experimental limitations, all the varieties are classed provisionally as day-neutral sorts. A number of these, including Early Mohawk, Longfellow, Masterpiece, Plentiful, Konserva, and Boston Yellow Eye, showed rather decided day-neutral tendencies.

As in the case of the green-podded bush sorts, no very distinctive change of behavior of wax-podded bush varieties resulted as the photoperiods were lengthened from 10 hours. Two varieties, Hodson Wax and Improved Stringless Kidney Wax, showed some delay in time of flowering, amounting to 10 days to 2 weeks or more, in response to the 18-hour photoperiod as compared with the shorter 10- and 12-hour photoperiods. This difference is so marked that there is reason to believe that a long photoperiod is actually unfavorable to the early flowering of these beans. It is interesting to observe that the plants become low twiners only in response to the 18-hour photoperiod, affording additional evidence that they were tending to become more purely vegetative in habit. There is always the uncertainty here, however, that the weak artificial light afforded the plants at the termination of natural daylight may have had some influence in stimulating these stem elongations. Brittle Wax is a typical day-neutral bean.

RESPONSES OF PHASEOLUS LUNATUS

The characteristics separating the bush and the pole forms of lima beans, as in the case of the *Phaseolus vulgaris* assemblage, are not always clearly defined in the field. The usual recognized grouping (table 3) has been followed for those varieties which have been studied.

Among the bush sorts, the Henderson variety (fig. 3, *A*) is the only one of the small-seeded sieva group representing the species *Phaseolus lunatus*. The rest are large-seeded sorts considered to belong to the variety *macrocarpus* or are hybrids. The pole sorts belong to the variety *macrocarpus*.

All the tested lima beans were day-neutral, and all tended to ripen their pods while still retaining their foliage, in this degree behaving as perennial types. The four pole varieties had very strong twining habits regardless of the length of the photoperiod (fig. 3, *B*). Florida Butter showed a tendency to delay flowering when the photoperiod reached 14½ hours. One of the hybrids, Baby Potato, showed a rather weakly twining behavior indicating that it was an indeterminate sort. The other hybrid, Baby Fordhook, showed some tendency to increase in height and to flower later in response to the full-day and the 18-hour photoperiod. The bush varieties showed no tendency to become true twiners whether the photoperiod was long or short, but certain of them showed some tendency toward the indeterminate habit of growth.

The characteristic of dwarf habit of growth of the lima bean is in part a response to certain conditions of environment. Bailey (*4*) in 1895, as a result of his studies of lima beans, stated that the Burpee bush lima variety, normally behaving as a very dwarf sort and showing little tendency to climb in the field, developed an excessive vine habit, with stems becoming 5 to 7 feet in height when it was forced under glass in wintertime. It is now known that this excessive growth in height is due to the elongation of the internodes. This tendency is less marked but present in summer as well as in winter.

The lima beans appear to be more warmth loving than the beans of the *vulgaris* group and show other fundamental differences in their physiology, one of these relating to the time required for planting and maturity of the pods. Whereas under field conditions the earliest bush varieties of the lima bean assemblage cannot mature sooner than 62 to 65 days, the earliest dwarf bush forms of *Phaseolus vulgaris* will mature in 45 to 50 days. The pole varieties of lima beans, some of which require more than 90 days to mature sufficiently for the table, are as much as 15 to 20 days later than the latest pole varieties of *P. vulgaris*.

RESPONSES OF MISCELLANEOUS PHASEOLUS SPECIES

Although there are perennial as well as annual species of *Phaseolus* only the latter were included in this study (table 4). The tested strain of the scarlet

Table 3.—*Responses of certain varieties of lima beans to length of day*

Type and variety	Year tested	Effect of daily exposure of—																		Length-of-day class
		10 hours		12 hours		12½ hours		13 hours		13½ hours		14 hours		14½ hours		Full day [1]		18 hours		
		Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	
		Days	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	
Bush:																				
Henderson	1940	30	10	30	11	30	12	30	14	30	17	30	13½	31	12	31 31	13 11	31	19	Day-neutral.
Burpee	1941	25	19	24	23	25	22	26	25½	28	31	26	40	25	26	28 28	30 28	37	35	Do.
Fordhook	1941	25	23	25	20	28	33	28	30	26	28	28	34½	26	40	31 29	24½ 24	30	30	Do.
Jackson Wonder	1940	31	14½	31	23½	31	24	31	17½	34	23	30	21	31	17	34 34	17 14	36	16	Do.
McCrea	1941	28	22½	25	26	25	22	26	26	26	31½	28	28½	26	32	29 29	28 35	29	31	Do.
Baby Fordhook	1941	29	13	28	13	29	14½	28	12	28	16½	28	18	28	13	37 37	13 19	37	25	Do.
Baby Potato	1940	31	17	31	21	31	15	33	17	29	25	31	14	34	12	35 35	17 13	36	18	Do.
Pole:																				
Challenger	1940	32	76	32	75	33	66	33	70	32	70	39	80	33	61	35 35	70 70	37	66	Do.
Florida Butter	1940	37	48	39	53	39	51	37	49	37	47	39	50	45	72	46 46	44 58	42	49	Do.
Leviathan	1940	33	66	32	52	35	70	35	72	35	70	35	70	36	58	38 38	66 72	44	68	Do.
Utah [2]	1940	30	80	34	76	32	71	32	71	31	77	38	77	34	75	36 36	65 60	37	45	Do.

[1] Values are given for the 2 controls, representing the full day.
[2] Possibly of Indian origin; sent writers from Utah; not listed in American seed catalogs.

FIGURE 3.—*A*, Henderson, a day-neutral bush lima bean, after being subjected from June 1 to July 25 to the hours of daylight shown on the buckets. The plants flowered as follows: 10- to 14-hours, 30 days; 14½-hour, full-day, and 18-hour, 31 days. *B*, Challenger, a day-neutral pole lima bean, after being subjected from June 17 to July 25 to the hours of daylight shown on the buckets. The plants flowered as follows: 10- and 12-hour, 32 days; 12½- and 13-hour, 33 days; 13½-hour, 32 days; 14-hour, 39 days; 14½-hour, 33 days; full-day (*c*), 35 days; 18-hour, 37 days.

runner bean behaved somewhat as an intermediate type, since the short day of 10 hours greatly delayed flowering (94 days), and the 18-hour photoperiod considerably delayed flowering. A single flower appeared in response to the 10-hour photoperiod, and no fruits had developed on these plants when examined during the last week of September. The twining habit was shown throughout, but this feature was most strongly developed when the plants had experienced a 10-hour or an 18-hour photoperiod.

The length-of-day behavior of the moth bean was studied in 1940 and 1941, and the results of both plantings indicate that it is a typical short-day plant in its photoperiodic behavior. It flowered most quickly in response to lengths of day of 10 to 13 hours, inclusive, with a very marked delay in response to all longer days. In 1941 the plants experiencing the full-day had not flowered on September 24, and the plants experiencing 18 hours of light each day flowered in neither 1940 nor 1941.

This bean is usually described as a diffuse, sprawling trailer, but its growth form appears to depend largely upon the length of day experienced. On photoperiods of 10 and 12 hours the plants were bushy with weak, decumbent stems; on all longer photoperiods except the full-day they developed a vining or twining behavior. The formation of elongate, trailing, or twining stems was especially marked in response to 18 hours of light each day.

There were great differences in time of maturity, as indicated by the drying of the pods and foliage upon the plants. On the shorter periods of 10 and 12 hours the pods and foliage had become dry by September 18. On this date an increasingly greener condition of the pods and foliage obtained as the photoperiods were lengthened to the maximum of 18 hours, and no flowering had occurred.

The behavior of the plantings of moth bean reported in table 4 indicate that these particular strains are adapted only to tropical or subtropical lengths of day. In these tests an increase in length of day of only one-half hour (from 13 to $13\frac{1}{2}$ hours) delayed flowering 44 days in 1940 and 23 days in 1941. In 1941 no pods were able to mature in response to any length of day as long as $13\frac{1}{2}$ hours. These results indicate that this bean can mature its pods only in low latitudes where a long frost-free season prevails. The tests indicate that it should grow well in Florida, lying between latitudes 25° and 31° N., if its length-of-day requirements are the only limitations. This bean appears to grow well in India, which lies mostly between latitudes 10° and 35° N., but even there it probably does best at latitudes below 35°. It is quite possible that strains which flower in response to much longer days exist. This characteristic would allow these beans to flower much earlier and to mature at higher latitudes.

The tepary bean is a native of Mexico and the southwestern United States. It is cultivated by the Mexicans and Indians at the present time and was probably much used by the latter in prehistoric times. This bean also is a short-day type, but with a rather high critical photoperiod for early flowering. It flowered in response to 18 hours of light in 79 days, and the plants were leafless with entirely dry pods 1 month later. The plants were mostly bushy and erect, but became more recumbent or weakly twining as the photoperiods were lengthened.

The adzuki bean also showed a short-day behavior, since the longer photoperiods delayed flowering. This bean is indigenous to Asia and is much cultivated in northern China and Japan. It is described as having an erect habit of growth, and this growth form developed on all photoperiods. In most of the tests the pods matured quickly, although the foliage long remained green on some photoperiods. The plants were dwarf on all photoperiods except the 18-hour where a very marked increase in height obtained. This species is adapted to latitudes at least as far north as 40°, wherever a sufficiently long frost-free season prevails to favor maturity.

The mung bean is a native Asiatic bean widely cultivated for food in China, India, Japan, and the Philippines. It, too, shows delayed flowering in response to the longer photoperiods, but more especially to the full-day and the 18-hour photoperiod. The greatest delay was shown when it experienced 18-hour photoperiods. The plants were bushlike and erect in response to all lengths of day except the 18-hour, where they became strong twiners. In all the tests except the 18-hour the pods and leaves became dry, or mostly so, by the last week of September. On this photoperiod the foliage remained green for a much later period. This bean, which was only slightly retarded in flowering on all photoperiods except the full-day at Arlington, Va., and the 18-hour photoperiod, could probably be grown to full maturity much farther north than the latitude of Washington, D. C., approximately 39° N.

The rice bean (fig. 4) is also a native of Asia, where it is sparingly cultivated in China and India. It showed the typical short-day behavior in two seasons, but with little or no delay in flowering until the full-day had been experienced. In 1940 the plants were erect and bushy in response to the photoperiods 10 hours to $13\frac{1}{2}$ hours, inclusive, but assumed the twining growth form in response to all longer photoperiods. The plants had become high twining in habit in response to the 18-hour photoperiod. They failed to flower on this photoperiod in 1940, and, although they flowered in 1941, flowering came too late to allow pods to mature. Judging from the behavior of the strains observed, this bean is not adapted to the latitude at 39° N. at which Arlington, Va., is located, and should therefore be grown much farther southward. However, earlier strains may be found in cultivation in Asia, and these having less rigid short-day limitations would favor the extension of these beans much farther northward.

The strain of urd bean grown in 1940 showed the day-neutral behavior, whereas that grown in 1941 showed a far greater delay in time of flowering. Whether this is a response to seasonal influences, such as temperature conditions, or the result of genetic differences associated with a somewhat dissimilar strain is not known. The plants were procumbent or characterized by a weak indeterminate or twining habit of growth on all the photoperiods. The pods and foliage matured quickly in response to nearly all the photoperiods. The responses of the urd bean would seem to indicate that it can mature its beans considerably farther north than the latitude of Arlington, Va., 39° N.

The several species of beans referred to in table 4 constitute a quite varied assemblage of material. Most of these species or varieties are more or less generally useful to man in their native country or elsewhere, because they are adjusted to certain favorable lengths of day which allow timely flowering and maturity before killing autumnal frosts prevail. It is probable that most of these species in their native country are grown over a latitudinal range as wide as their particular climatic requirements will allow, length of day being one of the most important among these. It is obvious that the introduction of any of these

TABLE 4.—*Responses of miscellaneous annual species of Phaseolus to length of day*

Name	Year tested	Effect of daily exposure of—																		Length-of-day class
		10 hours		12 hours		12½ hours		13 hours		13½ hours		14 hours		14½ hours		Full day[1]		18 hours		
		Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	
		Days	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	
Scarlet runner (*P. coccineus*)	1941	94	30	19	20	19	18	21	12	23	18½	26	21	29	36	33 33	13 13	35	37	Long-day.
Moth bean (*P. aconitifolius*)	1940	58	8	44	3½	46	5	49	8	93	32	98	29	123	37	101	9	([2])	28	Short-day.
Do.	1941	39	4	40	4	31	8	51	8	74	10	98	27	105	25	([3])	------	([2])	------	Do.
Tepary bean (*P. acutifolius* var. *latifolius*).	1941	30	17	29	12	31	16	30	15	31	17	33	16	([4])	------	54	12	79	28	Do.
Adzuki bean (*P. angularis*)	1941	33	6	33	6	34	4	33	5	36	6	36	7	33	6	65 65	7 7	70	31	Do.
Do	1940	36	5½	39	7	39	7½	34	8	37	8	37	8	40	7	46 46	10 12	67	24	Do.
Mung bean (*P. aureus*)	1940	30	4	32	5	30	5	30	7	30	7	36	8	38	8	46 46	9 11	74	42	Do.
Do	1941	31	6	30	6	30	6	29	5½	30	6	33	7	33	6	51 45	5 4	79	37	Do
Rice bean (*P. calcaratus*)	1940	31	3½	39	7	31	5½	31	5½	30	5	44	14	30	11	83 94	35 41	([3])	------	Do.
Do	1941	43	12	42	10	40	10	47	9	43	20	54	24	63	23	89 78	21 27	111	73	Do.
Urd bean (*P. mungo*)	1940	40	6	36	5	40	4½	32	5	47	8	36	5	46	7	44 42	7 7	46	10	Day-neutral.
Do.	1941	36	5	43	9	36	7	36	7	48	13	52	11	55	16	69 69	14 10	82	20	Short-day.

[1] When the full day was represented by 2 controls, values for both are given.
[2] No flowering.
[3] Not in flower on Sept. 24.
[4] No germination.

FIGURE 4. Rice bean (*Phaseolus calcaratus*), a pronouncedly short-day plant, after being subjected from May 28 to July 31 to the hours of daylight shown on the buckets. The plants flowered as follows: 10-hour, 43 days; 12-hour, 42 days; 12½-hour, 40 days; 13-hour, 47 days; 13½-hour, 43 days; 14-hour, 54 days; 14½-hour, 63 days; full-day (c), 78 and 89 days (2 controls); 18-hour, 111 days.

beans into new countries will require some forethought and experimentation if successful yields are expected.

A typical short-day bean, such as the moth bean, requiring relatively short days for timely flowering, can be grown successfully only at low latitudes. On the other hand, the mung bean should succeed much farther north.

RESPONSES OF MISCELLANEOUS LEGUMINOUS GENERA

The data of table 5 present the behavior of a number of legumes belonging to other genera than *Phaseolus*. Most of these plants are used for feeding stock, the plants being used in the green state or as hay, and as green-manure crops to be plowed under on poor or exhausted soils.

The jack bean (fig. 5) responded as a short-day plant, with retarded flowering on the full-day and the 18-hour photoperiods. While the plants are normally vigorous twiners, their heights showed marked decrease as the days were lengthened, until they had been reduced to low, erect bushes on the full-day and the 18-day photoperiod. Reduction of the twining and resulting lowered height appeared before delayed flowering was noticeable. Although the shorter photoperiods in general had caused a marked increase in height, delayed flowering had not appeared until the plants experienced the photoperiod of the full-day and 18 hours.

Reduction in size of the leaf and pod was very noticeable as a response to lengthened days, the smallest leaves and pods being associated with the full-day and the 18-hour photoperiod (see table 6).

The chickpea failed to germinate on the 10- to 12½-hour photoperiods inclusive. On all other photoperiods there was no significant difference in habit of growth, time of flowering, or final maturity of the pods and leaves. The indifference of this plant to length of day should favor its growth far northward, provided temperature conditions do not become unfavorable to the maturity of its seeds.

The yellow lupine behaved as a long-day species, but the 18-hour photoperiod appears to have hastened flowering. The plants were busy in response to all lengths of day and died early, in most instances setting very few pods. This lupine appears to have been adversely affected by the extreme heat and excessive rains of July.

In both 1940 and 1941 the asparagus-bean (fig. 6) showed little or no change in time of flowering in relation to the photoperiod, and in this and in all other respects it behaved as a day-neutral plant. The cowpea behaved somewhat as a short-day plant, showing a behavior in all respects very similar to that of the asparagus-bean.

The velvetbean (fig. 7) showed the typical behavior of a short-day plant, since flowering was greatly delayed in response to the full-day and the 18-hour photoperiod. Although the full-day plants flowered in 105 days, the plants given the 18-hour photoperiod had produced no buds in late September, when the experiments were discontinued. Although delayed flowering occurs in response to the full length of day, these plants had produced no pods September 18. At the same

TABLE 5. *Responses of miscellaneous legumes to length of day*

Name	Year tested	Effect of daily exposure of—																		Length-of-day class
		10 hours		12 hours		12½ hours		13 hours		13½ hours		14 hours		14½ hours		Full day [1]		18 hours		
		Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	Time required to flower	Height	
		Days	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	
Jack bean (*Canavalia ensiformis:* F. C.[2] 13855).	1941	63	43	65	28	79	69	61	29	65	27	56	29	68	27	88 78	12 12	83	18	Short-day.
Chickpea (*Cicer arietinum*)	1941	[3]		[3]		[3]		32	13	32	11	32	15	32	13	30	13	32	14	Day-neutral.
Yellow lupine (*Lupinus luteus*)	1941	88	8	79	10	76	12	[4]	5	75	18	79	9	79	9	[4]		52	9	Long-day.
Common vetch (*Vicia sativa*)	1941	[4]		[5]	25	[5]	7	[5]	4	[5]	24	[5]	12	[5]	9	[5]	4	88	46	[6]
Asparagus-bean (*Vigna sesquipedalis*)	1940	42	48	39	78	44	60	42	72	44	49	44	82	44	62	51 51	61 44	48	70	Day-neutral.
Do	1941	56	26	44	17	44	10	40	31	40	18	44	45	46	41	51 51	8 8	47	25	Do.
Cowpea var. Brabham (*Vigna sinensis*)	1941	54	20	49	12	58	17	58	21	53	23	55	22	65	26	66 67	10 13	63	46	Short-day.
Velvetbean (*Stizolobium deeringianum;* F. C.[2] 30703).	1941	44	[7] 15	44	[7] 14	44	[7] 14	51	[7] 9	47	[7] 11	67	[7] 10	46	[7] 10	105 105	22 22	[8]	[9] 33	Do.

[1] When the full day was represented by 2 controls, values for both are given.
[2] F. C. refers to accession numbers of Division of Forage Crops and Diseases.
[3] No germination.
[4] Died before flowering, supposedly from too much rain.
[5] Not in flower Sept. 17.
[6] More data needed.
[7] Bushy habit of growth.
[8] Buds noted Sept. 18, but these never developed beyond the bud stage.
[9] Tall viny growth.

FIGURE 5. Jack bean (*Canavalia ensiformis*), a distinctly short-day plant, after being subjected from May 24 to July 31 to the hours of daylight shown on the buckets. The plants flowered as follows: 10-hour, 63 days; 12-hour, 65 days; 12½-hour, 79 days; 13-hour, 61 days; 13½-hour, 65 days; 14-hour, 56 days; 14½-hour, 68 days; full-day (c), 78 and 88 days (2 controls); 18-hour, 83 days.

time pods had developed in abundance on all the shorter photoperiods. The pods and also the foliage of the plants remained green with no indications of maturity until the experiments were discontinued in late September.

The genus *Stizolobium*, including the velvetbeans, is a small one allied to the soybeans. A number of species are now cultivated in the United States. The best known of these is *S. deeringianum*, known as the Florida velvetbean when first described as new (5) in 1909.

The data of table 6 present measurements of the height of the plants, length and breadth of leaves and pod, and widths of the terminal leaflets of *Canavalia ensiformis* as influenced by the photoperiod. One of the most striking responses shown by *Canavalia ensiformis* was the growth form of the plants in relation to the photoperiod. The shorter photoperiods produced tall, twining plants, while the longer photoperiods produced a relatively dwarf, bush growth. This is a rather uncommon growth reaction. In the kidney beans (*Phaseolus vulgaris*) a complete reversal of this behavior was shown in the tests, the short days producing dwarf, bushy habits of growth, while the long days produced the vining, or twin-

FIGURE 6.—Asparagus-bean (*Vigna sesquipedalis*), a day-neutral plant, after being subjected from June 1 to July 25 to the hours of daylight shown on the buckets. The plants flowered as follows: 10-hour, 42 days; 12-hour, 39 days; 12½-hour, 44 days; 13-hour, 42 days; 13½-, 14-, and 14½-hour, 44 days; full-day (c), 51 days; 18-hour, 48 days.

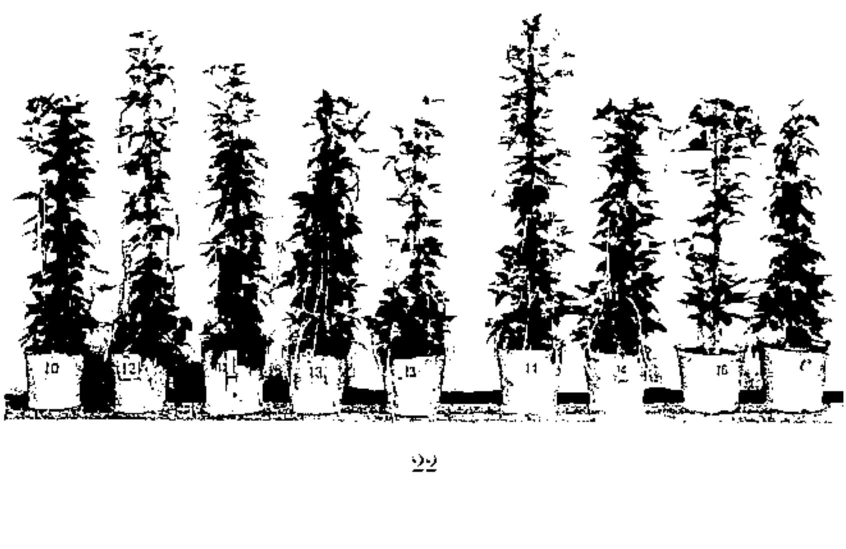


FIGURE 7.—Velvetbean (*Stizolobium deeringianum*), a pronouncedly short-day plant, after being subjected from May 24 to July 31 to the hours of daylight shown on the buckets. The plants flowered as follows: 10-, 12-, and 12½-hour, 44 days; 13-hour, 51 days; 13½-hour, 47 days; 14-hour, 67 days; 14½-hour, 46 days; full-day (c), 105 days. 18-hour plants budded in 117 days, but flowers never developed owing to the lateness of the season.

ing, habit of growth. A similar behavior was shown by *Stizolobium deeringianum* (table 5) and *Phaseolus polystachyus*.

It has generally been thought that the low intensity of the electric light supplementing normal day in the case of the 18-hour photoperiod may have been responsible in part for some degree of increased elongation of the stems of plants. No such elongation occurred in *Canavalia ensiformis*.

TABLE 6.—*Influence of length of day on plant, leaves, terminal leaflets, and pods of Canavalia ensiformis*[1]

Daily exposure to light	Leaf		Terminal leaflet		Pod		Plant	
	Length	Width	Length	Width	Length	Width	Height	Growth habit
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	
10 hours	13.4	11.0	6.2	4.3	9.5	1.2	43	Twiner.
12 hours	12.9	12.0	6.0	4.3	11.0	1.2	28	Do.
12½ hours	11.6	10.6	4.9	3.3	10.8	.8	69	Do.
13 hours	11.3	8.1	5.6	4.1	9.6	1.1	29	Do.
13½ hours	11.6	10.4	5.8	3.6	9.3	1.4	27	Do.
14 hours	11.8	9.0	5.1	3.8	10.5	1.2	29	Do.
14½ hours	10.3	11.0	5.0	3.6	9.8	1.2	27	Low twiner.
Full day[2]	7.5	7.5	3.2	2.5	7.3	.8	12	Bush.
18 hours	8.1	7.6	3.8	2.4	8.0	.8	18	Do.

[1] The 3 largest leaves on the 3 plants were measured, the length being taken from the point of attachment of the petiole to the stem, to the tip of the terminal leaflet. The maximum width of leaf was taken across the 2 basal leaflets. Length and width of the terminal leaflet apply to the maximum measurements of the blade of the leaflet. The length and width of the pods apply to greatest length and middle width.
[2] Average of 2 controls representing full day.

Another feature of the growth response of the plants in relation to photoperiod has been a very obvious increase in size of leaves, leaflets, and pods in response to the shorter lengths of day. The plants were not only more bushy in response to the longer photoperiods, but showed a greatly delayed flowering.

The more viny character together with the longer leaves and leaflets accompanying the shorter photoperiods suggested characteristics of etiolation sometimes following reduction in light intensity, but the greenness was quite normal in appearance. It is not obvious why shortened photoperiods should produce vininess in one plant and bushy growth in another species or why lengthened days should produce bushy growth in the former and vininess in the latter, with practically no change in time of flowering in some instances.

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