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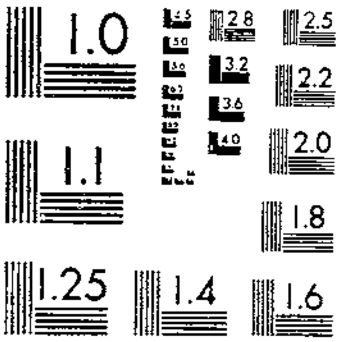
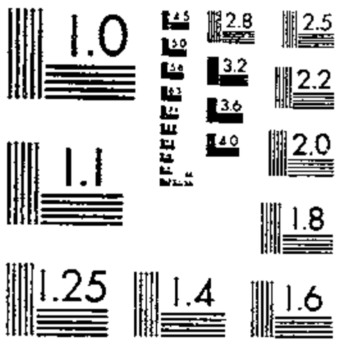


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



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Further Observations of the Response of Various Species of Plants to Length of Day[1]

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CONTENTS

INTRODUCTION

In the earlier studies[2] of the effects of different light periods, very few steps in length of day were available, owing to the lack of facilities that would allow for detailed investigation of small changes in length of day. Conclusions were based mainly upon tests involving very short days in contrast with the full length of day or very long days obtained by the use of artificial electric light. As a result, less was known of the upper or lower limits for flowering in members of the two groups than at present. As the work was extended a large mass of observations accumulated, making clearer the behavior of many species and varieties representing numerous families in relation to lengths of day increased by half-hour steps from 8 to 10 hours of light daily, up to the longest day of summer, and even to light periods beyond this point by the use of artificial light after sunset.

Because this later phase of the work has led to a better understanding of the concept of long-day and short-day plants and affords a basis for classification of many species into the two groups, it has

[1] Submitted for publication October 21, 1939.

[2] Garner, W. W., and Allard, H. A. effect of the relative length of day and night and other factors of the environment on growth and reproduction in plants. Jour. Agr. Res. 18: 553-606, illus. 1920.

——— further studies in photoperiodism, the response of the plant to relative length of day and night. Jour. Agr. Res. 23: 871-920, illus. 1923.

seemed advisable to embody all the results in brief form in the present bulletin.

It is obvious that plants must be subjected to lengths of day ranging from continuous illumination down to 8 or 10 hours of light by half-hour steps at least, to determine the upper and lower limits of flowering, if such limits exist. This has not always been found practicable, and future experimentation may show that many plants that undergo delayed flowering on the longer days will perhaps cease to produce flowers at some very high light-darkness ratio near continuous illumination.

A satisfactory, workable, and all-inclusive definition that will clearly separate the long-day from the short-day plants is not easily formulated. However, on the basis of response to daily light periods decreasing progressively from continuous illumination, a long-day plant is one that ceases to flower or shows delayed or less profuse flowering, whereas a short-day plant is one that begins to flower or shows hastened or more profuse flowering when the length of day is sufficiently shortened.

Although there may be a pronounced overlapping of the upper limits of flowering of the plants of the short-day group with the lower limits of the long-day group, the fact remains that the decrease of the daily light period ultimately causes the long-day plants to cease flowering entirely or to flower less readily or profusely. On the other hand, when the daily light periods are shortened sufficiently the short-day plants show a diametrically opposite tendency, flowering being initiated, hurried, or otherwise favored. These contrasting behaviors at the present time appear to be dependent upon fundamental differences in the physiology of the two groups and may be so regarded until further investigations have proved otherwise.

In addition to the long-day and short-day plants, there is a group that appears to be little affected by length of day. These have been designated as indeterminate or day-neutral plants. An indeterminate plant may be considered as one that flowers readily under all lengths of day.

A few plants have been found that will flower only between certain limits of length of day; it may be said arbitrarily between 12 hours and 16 hours of daylight. These may be termed intermediate plants, as they combine the behavior of both long- and short-day plants. A typical intermediate plant, then, can be regarded as one that begins to flower when the daily light period is decreased sufficiently below continuous illumination and ceases to flower at some shorter length of day.

CONTROLLING THE DAY LENGTH

In temperate latitudes a plant grown at any period of the year never experiences a constant length of day. From March 21, when the length of day from sunrise to sunset over the entire world is 12 hours, the days regularly increase in length, in the Northern Hemisphere, to the summer solstice, June 21. From this date until September 21 the days decrease in length, the decrements being the same as the increments before the summer solstice. The daily increments and decrements before and after the summer solstice are greater as higher latitudes are reached, and at or near the poles the short summer season may be a period of continuous daylight. At the Equator the days are slightly more than 12 hours in length at all times of the year. The extreme range in length of day from sunrise to sunset, at Washington, D. C., is approximately from 9 hours 26 minutes in winter to 14 hours 54 minutes in summer.

It is obvious that where it is desirable to study the responses of plants to fixed lengths of day, it is necessary to decrease or to lengthen the daily light duration artificially. In summertime when long days prevail it is a simple matter to shorten the daily light period experienced by plants by the use of ventilated dark chambers or houses in which the plants may be placed each day after they have received a given exposure of daylight. These may be constructed of any lightproof material, including black shade cloth, wood, or other material. In higher latitudes where the midsummer days reach a length of 14 hours or more, regulation of the daily light period by means of ventilated dark houses is not a difficult matter. Natural daylight is then available for all tests, and normally differences in quality and intensity are probably not significant in the comparisons of behavior of the plants.

If longer daily light exposures than naturally prevail at any season are desired, recourse must be had to artificial light to supplement the daylight from sunset. Although comparatively weak intensities supplementing this have produced results similar to very long periods of natural daylight, the higher intensities when employed have produced a more normal type of growth and reproduction. When artificial light alone is used throughout a test the factor of intensity aside from quality and duration becomes a very important one. Excessive heat radiation affecting the plants must then be met, and the higher wattage Mazda filament lights require suitable water jackets or screens to absorb the excess heat.

If a given daily duration is known to be favorable to flowering, it is essential that this be afforded the plants as a continuous period of illumination. If a daily exposure of 10 hours of daylight is decided upon, the plants should receive 10 hours of continuous light each day with 14 hours of continuous darkness. Five hours of light with a short intervening period of darkness of 1 or more hours followed by 5 additional hours of daylight, breaking up the 10-hour period into two 5-hour periods, will not induce early flowering in short-day plants for reasons that as yet have not been explained. The data in table 1 present the behavior of typical long-day, short-day, and indeterminate or neutral-day plants when darkened from 10 a. m. to 2 or 3 p. m., or for 4 hours and 5 hours, respectively.

It should be stated that in these and subsequent tests no examination of the growing points was made to determine whether the primordia of flowers were present at the time the tests began. In many of the tests the annuals were sowed directly, so that the seedlings were subjected to the experimental length of day from the outset. In these plants primordia could not form except where a favorable light period prevailed. Many of the native perennials were taken from the field or propagated in the greenhouse during the wintertime to obtain plants of suitable size and age for the tests. It is significant to note that in most instances the flowering behavior of these plants was similar to the material removed directly from the field to the tests.

TABLE 1.—*Effect of dark period in the middle of the day (10 a. m. to 2 p. m.) as compared with exclusion of early morning and late afternoon daylight and exposure to the full length of day*

Plants	Test began	10 hours of daylight: Time required for— Buds	10 hours of daylight: Time required for— Flowers	10 hours of daylight: Height	12 hours of daylight: Time required for— Buds	12 hours of daylight: Time required for— Flowers	12 hours of daylight: Height	Darkened in middle of day, 10 a. m. to 2 p. m.: Time required for— Buds	Darkened in middle of day, 10 a. m. to 2 p. m.: Time required for— Flowers	Darkened in middle of day, 10 a. m. to 2 p. m.: Height	Full length of day: Time required for— Buds	Full length of day: Time required for— Flowers	Full length of day: Height	Class
		Days	*Days*	*Inches*	*Days*	*Days*	*Inches*	*Days*	*Days*	*Inches*	*Days*	*Days*	*Inches*	
Althaea rosea Cav. (annual hollyhocks)	May 10		(1)			58	31		81	20		54	39	Long day.
Ambrosia:														
A. elatior L. (common ragweed)	June 11	12	21	10	12	21		47	57	29	42	72	44	Short day.
A. trifida L. (giant ragweed)	June 3	15	31	25	15	28	26	63	97	38	63	80	50	Do.
Bidens bipinnata L. (Spanish-needles)	do	15	25	14	16	25	19	86	98	17	66	72	32	Do.
Chrysanthemum orifolium Ram. (large late bronze chrysanthemum)	May 5	22	58	41	22	58	43	129	184	58	127	178	49	Do.
Convolvulus sepium L. (hedge bindweed)	May 19		(2)			(2)		54	67	56	35	49	45	Long day.
Euphorbia pulcherrima Willd. (poinsettia)	June 8		(3)			(3)		(4)	(5)		(6)	(5)		Short day.
Helianthus angustifolius L. (swamp sunflower)	May 10	35	51	28	35	51	25	115			107			Do.
Impatiens balsamina L. (garden balsam)	June 23	21	28	14	21	28	18	30	44	21	30	38	21	Indeterminate.
Perilla frutescens (L.) Britt. (perilla)	May 21	49	58	22	49	58	26	97	108	29	96	108	41	Short day.
Phleum:														
P. pratense L. (timothy, strain 1241)	Mar. 19		(7)			(7)		117	139	26	94	103	40	Long day.
P. pratense L. (timothy, strain 3937)	do		(1)			(8)		93	104	34	94	104	37	Do.
P. pratense L. (timothy, strain 11902)	do	104	128	29	92	110	31	71	89	42	65	84	40	Do.
Rudbeckia:														
R. hirta L. (black-eyed-susan)	Apr. 30		(1)		82	96	17	36	62	23	36	55	24	Do.
R. laciniata L	Apr. 22		(1)			(1)		76	112	40	62	104	75	Do.
Soja max (L.) Piper:														
Soybean, variety Peking	June 8		(3)			(3)			[9] 46	12		53	18	Short day.
Soybean, variety Biloxi	do		(3)			(3)			[9] 41	25		95	35	Do.
Tithonia rotundifolia (Ort.) Cass	June 19	19	36	58	39	64	53		144	96		144	120	Do.

[1] Rosette only.
[2] Vegetative only.
[3] No test.
[4] Darkened 5 hours in the middle of the day, i. e., from 10 a. m. to 3 p. m.; coloring about Nov. 1.
[5] Full color Dec. 25.
[6] Coloring about Nov. 1.
[7] Leafage only.
[8] Rosette and sterile stems only.
[9] Darkened 5 hours in the middle of the day, i. e., from 10 a. m. to 3 p. m.

It is obvious that in the majority of cases a period of darkness of 4 or 5 hours in the middle of the day does not greatly change the time of flowering as does a reduced continuous period of 10 or 12 hours of daylight. In most instances the behavior approaches that of the plants receiving the full length of day, except that frequently flowering may be more or less delayed, especially in long-day plants, and the stature of some is considerably reduced. This is all the more striking when it is considered that in all instances the plants received less than 11 hours of daylight even at the time of the summer solstice when the days were longest, the mean for the entire period of the test being considerably less. In respect to flowering the plants behaved as if the dark period of 4 or 5 hours had little or no effect. The reduced stature, which was usually shown, however, would indicate that the nutrition of the plants has been rather profoundly changed by reducing the hours of effective daylight.

The plants of Spanish-needles (*Bidens bipinnata*) experiencing the full length of day were nearly through flowering September 10 and dying from senility, whereas the plants darkened in the middle of the day were still green and healthy.

Plants with definite long-day or short-day requirements for flowering may change from purely vegetative expression to sexual reproduction or flowering within a very narrow range of lengths of day; this has been termed the critical length of day for flowering. Tests have repeatedly shown that an increase in length of day of only half an hour is sufficient to bring a plant to normal flowering from a persistent rosette condition. Such sharply contrasted differentiations of behavior within these narrow limits of daily duration would indicate that the critical length of day of some plants must embrace changes in the levels of daily duration of only a few minutes.

In the principal tests herein reported, lightproof or darkened houses (fig. 1) have been used throughout the summer to reduce the daily photoperiods, the exposures above 12 hours being increased by half-hour steps. The tests included daily exposures of 10, 12, 12½, 13, 13½, 14, and 14½ hours, and the full length of day, which at Washington, D. C., is nearly 15 hours in length on June 21. Obviously, these lengths of actual daylight cannot be utilized until the duration of the daylight period from sunrise to sunset has reached these values. The daily schedules followed in providing these day lengths are shown in table 2, together with the dates between which the corresponding day lengths occur naturally and the number of days during which they prevail.

TABLE 2.—*Daily schedule of daylight exposures employed for the various light periods shorter than the full length of day, the dates between which these day lengths occur naturally, and their duration at Washington, D. C.*

Daylight period (hours)	Exposed to daylight from—	In the dark house beginning—	Dates of natural beginning and ending of daylight period	Period daylight prevails	Daylight period (hours)	Exposed to daylight from—	In the dark house beginning—	Dates of natural beginning and ending of daylight period	Period daylight prevails
	A. m.	*P. m.*		*Days*		*A. m.*	*P. m.*		*Days*
10	6	4	Jan. 25–Nov. 17	296	13½	5	6:30	Apr. 23–Aug. 21	120
12	6	6	Mar. 18–Sept. 27	193	14	5	7	May 6–Aug. 7	93
12½	6	6:30	Mar. 29–Sept. 15	170	14½	5	7:30	May 23–July 22	60
13	5	6	Apr. 11–Sept. 3	145					

From the figures it is evident that the longest daily exposures using natural daylight, namely 14 and 14½ hours, are effective for only 93 and 60 days, respectively.

In all tabulations of behavior that will be presented, the full length of day has been taken as a standard of behavior or as the normal expression of the plant to natural conditions of daylight. This, however, is a complex and variable standard representing a regularly changing day length with constantly increasing daily increments of light duration up to the summer solstice and a series of constantly decreasing lengths of day after the summer solstice. Such a standard may, in many instances, represent a series of opposing forces with

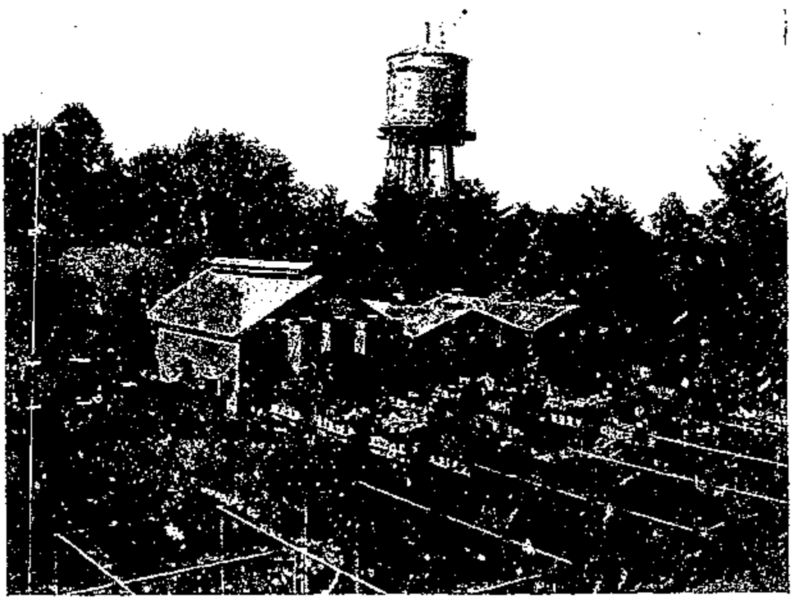

FIGURE 1.—View of the large lightproof houses at Arlington Experiment Farm, Arlington, Va., used to keep the plants in darkness for different periods. The plant containers remain on trucks running in and out of the darkened houses on iron tracks. The small cases at the left are used for localization tests and demonstrations, different branches of the same plant being subjected to different constant light periods each day.

respect to flowering, as the length of day is increasing or decreasing before or after the summer solstice. A simpler and truer standard of comparison would be one where the maximum length of day of the season was prolonged unchanged throughout the course of the experiment, to be used as a comparison with the full length of day. Unfortunately, this cannot be had without the use of artificial light to supplement the natural daylight, which then introduces new complications involving especially intensity and quality of the light.

It should not be inferred from the tables that the final flowering of the short-day plants experiencing 14 or 14½ hours was a response to these lengths of day. Final flowering of all the short-day plants, even on those indicated lengths of day that may be well above the critical for flowering, is a natural result of the ultimate seasonal reduction in length of day to the critical. Obviously, where a short-day plant subjected to a given length of day has flowered before the controls, this length of day has been below the critical. If it has flowered no sooner than the controls, it has not been subjected to a length of day above the critical.

From the fact that the days advance in length to the maximum at the summer solstice and then decrease, each group of plants, the long-day, the short-day, and the indeterminate or day-neutral plants unaffected by lengths of day, should show rather characteristic responses to these conditions. Actually, the truly indeterminate plants are little affected, as neither short days nor long days exert a selective action on flowering. The short-day plants, however, where flowering is favored by lengths of day below the maximum day lengths of the solstice, must await the passing of the longest days of midsummer, so that the greatest delay in flowering is indicated for the short-day plants. The poinsettia, which has a critical length of day near 12 to 12½ hours, as well as many chrysanthemums, ordinarily cannot flower until well into November or December. The long-day plants find the increasing length of day favorable to flowering and are forced into flower either at the height of the midsummer solstice or shortly afterwards. An inspection of all the tabulated data shown will indicate these differences of behavior in response to the inconstant full length of day.

EXPERIMENTAL DATA AND DISCUSSION

In the following tabulations, the response to length of day of a great variety of plants is presented. Only the more salient features of behavior are mentioned. An attempt has been made to determine the length-of-day class to which each belongs. In some cases, however, the classification is tentative, pending further tests with higher light and darkness ratios or perhaps continuous illumination.

It may be well to emphasize the fact that length of day is but one of many factors that may affect the responses of plants. All the higher flowering plants have potentialities of reproduction, but the expression of this depends upon proper nutrition, oftentimes particular temperature levels, intensity and perhaps quality of light, length-of-day requirements, and there may be other factors at present not well understood. It is obvious that with some plants, such as the sugar beet, length of day cannot exert its full influence until the plants are grown under temperature conditions also favorable to flowering. This fundamental principle of behavior has been kept in mind throughout the course of the experiments, the data of which are herein presented. In most of the tests full summer daylight was utilized and normal, vigorous growth was maintained. The length-of-day responses were clear-cut and decisive for a great variety of plants where the temperature conditions of a simultaneous series varied only slightly or not at all.

The sort of flower stem developed, whether erect, declined, or even prostrate, is markedly influenced by particular lengths of day, as has been shown by timothy, Canada bluegrass, Kentucky bluegrass, and some other plants. This striking behavior in relation to the different lengths of day is shown for three flowering plants in table 3.

TABLE 3.—*Character of growth, whether prostrate, decumbent, or erect, under different daily periods of illumination*

Plants	Test began	Length of the daily light exposure								Class
		10 hours	12 hours	12½ hours	13 hours	13½ hours	14 hours	14½ hours	Full length of day	
Heliopsis helianthoides pitcheriana Fletcher (Compositae).	Apr. 9	A few flowers, stems prostrate.	A few flowers, stems prostrate.	Flowers abortive, stems prostrate.	Flowers abortive, stems prostrate.	New flowers, erect.	Many flowers, erect.	Many flowers, erect.	Many flowers, erect.	Long day.
Anagallis linifolia L. (Primulaceae).	May 25	No buds, stems prostrate.	Many flowers, stems prostrate.	No test	Many flowers, stems prostrate.	No test	do	No test	Many flowers.	Do.
Chryopsis mariana (L.) Nutt., golden-aster (Compositae).	Mar. 27	Many flowers, decumbent.	Many flowers, decumbent.	Many flowers, decumbent.	Many flowers, erect.	Many flowers, erect.	do	Many flowers, erect.	Many flowers, erect.	Short day.

The intensity of the leaf green or chlorophyll of soybeans and many other plants has varied very noticeably, depending upon the length of day experienced by the plants. At the critical length of day for flowering, near 12.5 hours, the poinsettia has shown striking differences in the red coloration of the floral bracts immediately subtending the inflorescence. A day length of 10 to 12 hours favors a high intensity and uniformity of coloration. With 12.5 to 13 hours of light, flowering was retarded and the floral bracts remained green or were irregularly colored or weakly suffused with crimson in part (table 4).

TABLE 4.—*Coloration of the foliage of some species of plants under different light exposures*

Plants	10-hour day	Darkened in the middle of the day from 10 a. m. to 2 p. m.	Darkened every other day	Full length of day
Euphorbia pulcherrima Willd.	Much darker green than under full length of day.	Much darker green than under full length of day.	Much darker green than under full length of day.	Normal green.
Perilla frutescens (L.) Britt.	Almost no red color; nearly green.	Almost as dark red as under full length of day.	Almost green; little red coloration.	Rich dark-bronze red.
Tithonia tubaeformis (Ort.) Cass.	Almost as dark green as under full length of day.	No test.	Paler green than under full length of day.	Normal green.

CHRYSANTHEMUMS

The data presented in table 5 deal with the behavior of 14 named varieties of chrysanthemum, including both the Japanese and the garden pompon sorts.

On the shorter lengths of day, the primordia as well as the visible buds developed with little delay into normal flower heads, and buds and flowers continued to form all summer. On the longer day of 13 hours these early buds were usually transformed into vegetative structures, the involucral bracts oftentimes becoming elongated and leaflike. These buds usually were overtopped finally by the new growth and late buds that developed in response to the normal shortened length of day of late summer and autumn. On the day lengths in excess of 13 hours, few early buds appeared, as growth of the primordia was inhibited. These plants produced visible buds and flowered only in response to the short autumnal days.

The variety known as October Gold was particularly striking in its behavior (fig. 2). Young vigorous plants, received from the nurseryman (Dreer) in 2-inch pots March 19, were transferred to 3-inch pots on that date. These were transplanted into large buckets and placed under test conditions beginning March 29, when the plants were about 14 inches in height and small buds were already in evidence. Under the shorter lengths of day, i. e., 10, 12, and 12½ hours, the buds continued to grow and flowered normally without interruption (table 5). Under these shorter day lengths new buds continued to form and produced flowers throughout the summer. A length of day of 13 hours induced a slowing down in the growth of these early buds, flowering was sparse and much delayed, and some of the younger buds apparently remained entirely dormant. Under lengths of day

TABLE 5.—*Effect of length of day on formation of flower buds,*[1] *time of flowering, and the height of various varieties of chrysanthemums in a test begun May 8*

Variety and source	Effect of daily light exposure of—																							
	10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day		
	Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—		
	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height
	Days	*Days*	*Inches*	*Days*	*Days*	*Inches*	*Days*	*Days*	*Inches*	*Days*	*Days*	*Inches*	*Days*	*Days*	*Inches*	*Days*	*Days*	*Inches*	*Days*	*Days*	*Inches*	*Days*	*Days*	*Inches*
Bright Eyes (Dreer)	26	90	9	24	71	12	24	84	12	24 84	---- 166	---- 21	24 92	---- 171	---- 26	118	178	27	123	176	38	123	176	36
October Gold (Dreer)	19	54	16	24	59	14	24	61	16	24	74	19	[2] 31 ----	168 ----	---- ----	28 102	---- 167	---- 35	38 116	---- 173	---- 44	123	171	34
Lucifer (Dreer)	26	61	22	31	69	22	26	84	28	38	82	25	39 103	---- 160	---- 36	(3) 106	---- 173	---- 48	(3) 123	---- 173	---- 49	123	173	44
Ruth Hatton (Dreer)	19	48	15	24	59	15	24	59	19	24	68	23	24	76	23	28	77	23	41	99	29	46 123	103 166	---- 22
Yellow Normandie (Dreer)	21	54	16	24	54	13	24	54	16	25	59	14	24	56	20	38	73	19	38	78	20	46	71	18
Zella	21	61	18	26	63	18	25	66	21	24	66	24	24	136	31	24 106	---- 171	---- 39	123	164	46	123	164	44
Louise M. Stimson (pompon, U. S. Dept. Agr.)	19	43	11½	19	43	13½	24	61	14	24	66	16	24	76	17	28 116	---- 169	---- 34	123	169	43	123	167	33
Mrs. M. M. C. Taylor (pompon, U. S. Dept. Agr.)	26	70	21	31	71	20	31	81	24	31	88	28	[2] 38 ----	---- 146	---- 37	97	164	46	123	168	54	123	164	43
Henry A. Wallace (Japanese, U. S. Dept. Agr.)	28	62	19	26	76	20	33	96	24	33	146	21½	39 101	---- 178	---- 31	118	182	37	123	182	50	130	182	40
George Billups (pompon, U. S. Dept. Agr.)	24	62	19	26	66	21½	25	73	24	24	87	25	[2] 28 ----	---- 160	---- 33½	116	171	35	123	171	44	123	168	36
Billy (pompon, U. S. Dept. Agr.)	24	56	18	24	61	20	24	61	19	24	59	22	24 103	87 160	---- 35	31 105	---- 168	---- 40	123	164	54	123	168	36
Francis Brawn (pompon, U. S. Dept. Agr.)	21	54	12	24	61	16	24	68	18	24	76	16	24	112	17	33 106	---- 176	---- 29	123	176	40	123	173	34

Chattanooga (Japanese, Gude Bros., Washington, D. C.)	-----	(4)	-----	41	94	23	49	171	27	59	173	-----	104	188	40	123	188	45	123	188	48	137	188	43
Columbus Dispatch (Japanese, Elmer D. Smith Co.)	-----	(4)	-----	27	73	21	28	80	21	{31; 109}	173	33	[2] 38	187	39	}123	187	45	123	187	53	123	186	45
Helen Eakin (pompon, U. S. Dept. Agr.)	32	73	17	33	76	17	38	98	20	38	168	24	116	178	33	118	173	34	123	178	38	130	181	31
Evening Star (Japanese, Elmer D. Smith Co.)	31	76	21	31	80	22	39	96	24	38	111	25	{80; 102}	164	41	}110	176	45	123	174	52	123	174	40
Ilo (Japanese, U. S. Dept. Agr.)	19	54	19	24	59	18	24	71	20	25	82	25	28	123	23	{41; 106}	166	36	41; 123	181	38	[3] 123	176	36
Iowa (Japanese, U. S. Dept. Agr.)	28	73	16	28	76	18½	28	98	20	34	136	19	38	{18[1]}	34	123	182	36	123	181	44	102; 123	185	40
Fern McKenney (pompon, U. S. Dept. Agr.)	24	54	17	24	54	18	24	53	21	24	68	23	26	117	27½	{(3); 106}	168	35	(3); 123	169	46	}123	171	41
General Pershing (Japanese, U. S. Dept. Agr.)	26	71	21	31	80	25	28	87	26	34	123	29	38	168	44	{38; 116}	178	44	}123	178	60	123	176	38

[1] When 2 periods of time are given for the appearance of flower buds, the first indicates the time of appearance of early buds that developed apparently from primordia laid down during the short days of the springtime, whereas the second or later period indicates the appearance of late buds arising from primordia laid down in response to the short days of autumn.

[2] Buds appeared sometime in August.

[3] Buds appeared sometime in June.

[4] No test.

of 14, 14½ hours, and the full length of day, reaching a maximum June 21 of 14 hours 54 minutes from sunrise to sunset, flowers did not appear until October 22 to 24. Some of the first-formed buds noticeable May 29 at the beginning of the tests remained dormant until late autumn. Others gradually developed into vegetative shoots or became so weakened that they were never able to develop normal open heads, and many of them died. Free and normal flowering finally took place from late buds developed September 6 in response to the short seasonal lengths of day of autumn. At the same time many of the early buds that had remained practically dormant from about June 1 to mid-October, a period of 19 to 20 weeks, continued their

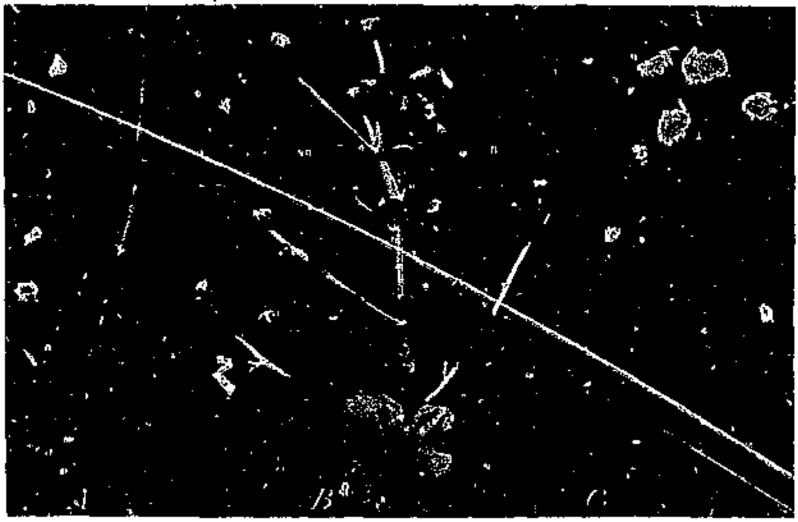

FIGURE 2.—Chrysanthemum, variety October Gold, showing the adverse effect of increased length of day upon the embryonic buds laid down in response to the short days of early spring before the tests began in early May. *A*, Buds forced into vegetative expression by a daylight period of 13½ hours. These were abnormal, the bracts of the head becoming foliar structures, and the peduncles, normally nearly naked, bearing leaves. These buds died without flowering or remained small and depauperate with no further enlargement. Normal buds appeared in early autumn, in response to the short days, and flowered October 23. *B*, Buds exposed to 13 hours of daylight each day, which produced normal flowers but were delayed in flowering until July 21. *C*, Buds exposed to a 10-hour day. These continued normal, undelayed development and flowered July 1. (Photographed Aug. 20.)

growth and flowered, together with the buds that were formed in early September and produced flowers without arrested development.

The same behavior was also strikingly shown by the variety Bright Eyes; the early buds formed in mid-June did not flower until September 8 on the 13-hour day and not until October 23 on the 13½-hour day. Although these early buds remained dormant throughout the entire summer, they produced mostly normal flowers. Days of 14 and 14½ hours in length were too long to allow the early buds to develop into flowers. In these tests, normal buds appeared September 1 and 8, respectively, followed by open flowers on November 2.

The delayed flowering of the early buds is a rather remarkable behavior. The chrysanthemum is a flower that is favored by cool

A *B* *C*

The Louise M. Stimson variety of chrysanthemum. *A*, 13½-hour day, the normal bronze-red color well developed; *B*, 13-hour day, normal red color very slight; *C*, 12½-hour day, no red color developed, rays yellowish due to lack of anthocyan.

weather, but in these tests the buds were forced to endure high summer temperatures. It is quite probable that cool temperatures together with short days would have favored the survival and development into normal flowers of a far greater percentage of these early buds. It is clear that all varieties of chrysanthemum here considered belong to the short-day type.

This behavior of arrested development involving large, well-formed buds in the chrysanthemum is significant, for it is obvious that an unfavorable length of day may cause a striking delay or even a dormant condition that can persist for months or until a favorable length of day accompanying the natural swing of the season has effected a release in the direction of continued development and ultimate flowering (fig. 3).

Remarkable changes in the normal coloration of the flowers of chrysanthemum have taken place in response to length of day. The

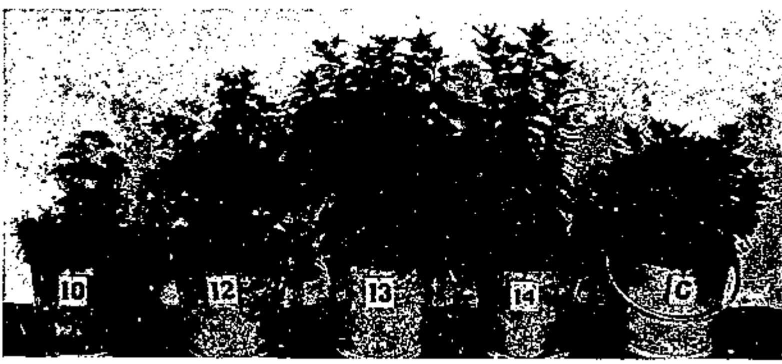

FIGURE 3.—Garden chrysanthemum, variety Helen Eakin, a pompon originated by the United States Department of Agriculture. The plants flowered under different day lengths as follows: 10 hour, July 6; 12 hour, October 14; 13 hour, October 19; 14 hour, October 31; full day (C), October 31. Tests began June 5; photographed August 28.

behavior of the variety Louise M. Stimson has been particularly striking. The rays of this variety normally are bronze red in coloration, but when grown under the shorter daylight exposures of 10, 12, and 12½ hours all the heads were a pale, bleached yellow, with no hint of the usual red. With 13 hours of light a few of the heads had assumed the normal bronze-red coloration in part. With 13½ hours of daylight each day some pale-yellow heads were present, but there were many bronze-red heads in evidence. All the longer day lengths produced heads of normal coloration. A number of other varieties showed these color changes to less degree. These color relations are shown in plate 1.

COSMOS, CALENDULA, GAILLARDIA, GUIZOTIA, TAGETES, AND ZINNIA

The responses to day length of certain species and garden varieties of *Cosmos*, *Calendula*, *Gaillardia*, *Guizotia*, *Tagetes*, and *Zinnia* are summarized in table 6.

The yellow-flowered species, *Cosmos sulphureus*, is now recognized as occurring in at least two distinct garden forms, the late form deferring flowering until arrival of the short autumn days, which are necessary as the releasing mechanism (fig. 4). Plants of the late variety subjected to 10 and 12 hours of light daily died quickly following hastened senility, being entirely dead October 2. The plants with 13 hours of light showed weak flowering, whereas those receiving 13½, 14, and 14½ hours of light and the full length of day were not in

FIGURE 4.—*Cosmos sulphureus* Cav. Late strain. A typical short-day strain flowering under various day lengths as follows: 10 hour, June 15; 12 hour, June 22; 12½ hour, June 30; 13 hour, June 26; 13½ hour, August 18; 14 hour, 14½ hour, and full day (C), October 16. This strain is adapted only to the shorter days and warm autumnal days of the South. Tests began May 14; photographed June 30.

full bloom until September and October. This is definitely a short-day form.

Within recent years a variety, Orange Flare, has been developed, which flowers in response to all lengths of day in these tests, but with increasing delay under the longer daily light periods (fig. 5). Under the full length of day and 14 hours of light daily, there was a delay of 18 days in time of flowering as compared with the plants receiving

FIGURE 5.—*Cosmos sulphureus* Cav. Early Orange Flare (Dreer). A strain of yellow-flowering cosmos little affected by lengths of day up to 15 hours at least. Flowering under the various day lengths was as follows: 10 hour, June 13; 12 hour, June 15; 12½ and 13 hour, June 18; 13½ hour, June 27; 14 hour, June 29; 14½ hour, June 30; full day (C), June 24. This strain is early flowering and suitable for higher latitudes because it is a short-day plant with a high critical limit for flowering. Tests began May 20; photographed June 30.

10 hours of light each day. This would indicate that the plant is mildly of the short-day type.

Three distinct varieties of *Cosmos bipinnatus* have been grown, all of which have flowered eventually on all the daily light periods of the tests. The Autumn Giant Crimson variety of cosmos shows a decided delay in flowering on the longer light periods, together with a marked increase in purely vegetative growth or height. The plants on the short light periods of 10 and 12 hours quickly reached senility and died, but those on the longer periods were still in full flower and in a vigorous growing condition. The plant thus behaves as a typical short-day type in its flowering behavior. The Extra Early Colossal Crimson variety has shown a less marked short-day behavior, and the Extra Early Express Pink variety has exhibited little or no delay in flowering and no increase in stature as the daily light periods have been increased. To this degree it is a typical indeterminate type. Extra Early Colossal Crimson has shown only a slight delay in flowering on the longest light periods, but a marked increase in height has taken place. In these respects the plant is not typically an indeterminate type even though flowering is not greatly delayed as the days are increased in length.

The two varieties of calendula are characteristically indeterminate in their flowering behavior, both the Campfire Sensation and the Lemon King in growth and time of flowering responding as typical indeterminate types.

The gaillardias, Burgundy and Indian Chief, have been tentatively classed as indeterminate in their requirements for flowering. The Burgundy produced very few flower stems on the shorter light periods, but a heavy growth of leafage developed. The plants were strikingly more floriferous on the longer light periods, showing a tendency toward the long-day habit in their flowering requirements. The Indian Chief variety was floriferous in all tests, but the plants grew but little under 10 hours of daylight each day. Flowering appears to have been favored by longer days.

Seed of *Guizotia* (niger seed), valuable for the drying oils contained in the seed, was obtained from the Division of Drug and Related Plants, Bureau of Plant Industry. Two lots of this seed were grown, one sown in the greenhouse April 5 and germinating April 8, the other sown directly on the tests May 28 and germinating June 1. Plants of the first-sown seed were placed upon the tests May 13, when 4 to 5 inches high. The behavior of these two lots of plants was so different, as shown in relation to the various lengths of day throughout, that some discussion seems necessary.

It would appear that the normal behavior of *Guizotia* is best indicated in those tests where the seed was sown May 28 in the various day-length tests. In this series flowering was greatly hastened by the shorter lengths of day. An increase of only one-half hour of light daily, i. e., from a length of day of 13½ hours to 14 hours or more, delayed flowering 37 days. It is evident that this particular strain of *Guizotia* is a plant of pronounced short-day habit, as plants experiencing the full length of day were also delayed in flowering until September 3.

In contrast with this sowing of May 28, the sowing of April 5, entering the tests May 13 as well-developed young plants, showed a readiness to flower about equally quickly from lengths of day of 10 hours to 14½ hours. The explanation appears to be that these earlier-sown plants came within the influence of seasonal lengths of day short enough to impress a strong flowering stimulus upon all the plants before the tests finally began May 13. At this time the length of day from sunrise to sunset was 13 hours 6 minutes, even below the day length of 13½ hours, which does not occur at Washington until May 22. An inspection of the planting of May 28 indicated that no great delay in flowering took place until the length of day was increased to more than 13½ hours.

TABLE 6.—*Effect of length of day on formation of flower buds, time of flowering, and height of Cosmos, Calendula, Dahlia, Gaillardia,*[1] *Guizotia, Tagetes, and Zinnia*

Plants	Test began	Effect of daily light exposure of—																								Class
		10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day			
		Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			
		Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	
Calendula:																										
C. officinalis L. (Campfire Sensation)	May 9	*Days* 26	*Days* 42	*In.* 9	*Days* 26	*Days* 41	*In.* 13	*Days* 26	*Days* 41	*In.* 15	*Days* 26	*Days* 41	*In.* 15	*Days* 26	*Days* 47	*In.* 20	*Days* 26	*Days* 41	*In.* 18	*Days* 26	*Days* 44	*In.* 20	*Days* 26	*Days* 41	*In.* 17	Indeterminate.
C. officinalis L. (Lemon King)	May 29	31	50	12	16	37	11	----	[2]	----	16	33	14	----	[2]	----	15	28	14	----	----	---	22	33	17	Do.
Cosmos:																										
C. bipinnatus Cav. (Autumn Giant Crimson)	May 4	13	24	25	13	28	31	13	19	17	17	31	32	19	38	38	35	52	60	35	47	56	64	80	86	Short day.
C. bipinnatus Cav. (Extra Early Express Pink)	May 7	10	17	19	10	24	36	10	17	19	10	19	20	10	15	----	10	21	19	10	24	26	10	19	17	Indeterminate.
C. bipinnatus Cav. (Extra Early Colossal Crimson)	do	10	19	20	10	26	31	10	25	27	10	21	21	14	28	32	28	46	57	19	31	55	26	40	48	Short day.
C. sulphureus Cav. (Klondyke, late)	June 6	17	27	28	19	33	32	----	[2]	----	20	35	34	83	106	74	117	135	80	117	135	84	117	135	84	Do.
C. sulphureus Cav. (Orange Flare, early)	May 15	20	34	30	20	34	30	20	35	24	27	40	31	24	39	34	29	45	42	35	52	38	35	52	38	Do.
Dahlia:																										
D. rosea Cav. (Coltness Hybrids)	May 7	21	35	7	39	51	13	35	51	10	28	47	16	35	51	16	35	51	----	28	49	14	28	45	21	Indeterminate.
D. rosea Cav. (Delice variety)	June 1	44	54	13	44	57	22	----	[2]	----	----	----	[2]	----	[2]	----	----	[2]	----	----	[2]	----	89	129	----	Short day.

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Gaillardia:																									
G. aristata Pursh (Burgundy)	Apr. 28	15	30	5½	27	49	13	23	45	8	25	51	14	18	36	14	27	49	22	22	39	15	21	46	23	Indeterminate.
G. pulchella var. *picta* (Sweet) Gray (Indian Chief)	May 27	8	28	4	24	45	15	12	24	8	18	45	14	16	37	16	18	36	14	13	35	14	14	33	14	Do.
Guizotia:																									
G. abyssinica (L. f.) Cass (niger seed)	June 1	24	39	31	24	36	38	27	39	43	43	55	50	43	57	57	74	94	72	74	94	77	78	94	69	Short day.
Do.	May 13	16	28	32	16	28	20	16	30	38	16	28	34	23	39	38	40	60	57	15	25	23	15	21	15	Do.
Tagetes:																									
T. erecta L. (African marigold, double annual)	May 7	15	31	20	17	36	28	17	38	32	21	38	34	24	43	40	28	53	42	32	59	46	36	59	41	Do.
T. erecta L. (African marigold, Guinea Gold)	May 1	31	75	16	32	52	25	38	52	28	34	55	32	38	59	34	40	61	31	39	63	40	45	68	37	Do.
T. erecta L. (marigold, Legion of Honor)	May 20	14	29	11½	13	33	13	12	30	11	23	47	18	17	49	15	17	47	14	19	47	14	15	38	14	Indeterminate.
T. erecta L. (African marigold, Dreer's Orange Prince)	May 16	---	31	18	---	35	20	---	(2)	---	---	(2)	---	---	(2)	---	---	(2)	---	---	(2)	---	(4)	---	---	Do.
T. signata Bartl. (Dreer's French marigold)	June 16	---	(3)	8	---	(3)	10	---	(2)	---	---	(2)	---	---	(2)	---	---	(2)	---	---	(2)	---	---	(3)	7	Do.
T. signata Bartl. (pumila variety)	May 16	15	23	4½	16	24	5	---	(2)	---	---	(2)	---	---	(2)	---	---	(2)	---	---	(2)	---	33	---	---	Do.
Zinnia:																									
Z. elegans Jacq. (double California Giant)	May 7	14	28	19	14	28	23	14	28	26	14	30	21	14	32	23	15	35	26	17	35	25	19	37	30	Do.
Z. haageana Regel (Hald)	May 21	13	26	10	15	30	13	---	(2)	---	14	30	13	---	(2)	---	18	36	18	---	(2)	---	15	33	12	Do.
Z. scabiosa Hort.	May 27	9	26	15	12	31	18	12	26	16	12	24	16	21	40	26	14	28	17	18	35	28	15	35	20	Do.

[1] Seed of the 2 strains of *Guizotia* (niger seed) furnished by the Division of Drug and Related Plants, U. S. Department of Agriculture.
[2] No test.
[3] Flowered previous to test (10 hour, June 9; 12 hour, June 12; full length of day, June 8).
[4] No buds had appeared June 18.

From the behavior of the particular strain of *Guizotia* in the tests it is evident that this could not well be grown much farther north to secure good seed production before frost, and even in the latitude of Washington the hazard may be too great. The growing of this plant somewhat farther south, however, should favor vigorous seed production before frost.

All the marigolds in the tests, except the large African marigolds of the species *Tagetes erecta*, have shown a more or less indeterminate behavior in their flowering (fig. 6). The larger African marigolds, however, showed a slight delay in flowering on the longer light periods.

The three zinnias in the tests behaved more as indeterminate types in their flowering with respect to length of day, rather than as long- or short-day plants.

Of the dahlias, the variety Coltness Hybrids has been classed as an indeterminate-day plant, although growth and flowering were very

FIGURE 6.—*Tagetes erecta* L. African marigold var. Guinea Gold (Dreer). A plant of rather indeterminate habit, but flowering with least delay on the shorter day lengths. Flowering under different day lengths was as follows: 10 hour, July 15; 12 and 12½ hour, June 22; 13 hour, June 25; 13½ hour, June 29; 14 hour, July 1; 14½ hour, July 3; full day (C), July 8. Very long and very short days appear to delay flowering. Tests began May 15; photographed June 30.

poor with 10 hours of light daily. In all the other tests there was good growth, and the time of flowering and the abundance of blooms showed little variation on the longer periods. The variety Delice is definitely a late, short-day type.

WILD NATIVE SPECIES OF COMPOSITAE

The data presented in table 7 deal with a number of native wild Compositae common to the District of Columbia section. Wingstem (*Actinomeris*) shows a progressive delay in flowering with increasing length of day, plants receiving 14 and 14½ hours of light daily flowering 1 month later than those receiving 10 or 12 hours of light. This plant shows the behavior of a short-day plant. Rosinweed (*Silphium*) flowers somewhat more quickly as the light periods increase in length, and it is indicated that flowering is favored by an increasing length of day (fig. 7). The two ragweeds (*Ambrosia elatior* and *A. trifida*) are now fairly well known to most persons who are affected by autumnal hay fever. Both are short-day plants, but in nature the giant ragweed (*A. trifida*) flowers earlier than the low ragweed (*A. elatior*). This relationship is also indicated where the seasonal length of day has been artificially shortened to 14½ or 14 hours in the tests.

TABLE 7.—*Behavior of some wild native species of Compositae in response to length of day*

Plants	Test began	Effect of daily light exposure of—																								Class
		10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day			
		Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	
		Days	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	
Actinomeris alternifolia (L.) DC. (wingstem)	May 16	26	41	17	26	42	23	-----	(1)	----	40	54	24	41	62	34	51	73	38	44	70	48	85	114	56	Short day.
Ambrosia:																										
A. elatior L. (low ragweed)	May 11	23	38	11	23	38	17	24	42	10	35	51	27	35	46	36	43	77	48	56	78	38	69	100	40½	Do.
A. trifida L. (high ragweed)	May 18	36	54	20	32	44	24½	27	40	27½	36	52	37	50	69	48½	37	63	49½	37	60	48	88	103	50	Do.
Bidens bipinnata L. (Spanish-needles)	June 3	15	25	12	16	25	19	-----	(1)	----	15	27	20	18	27	20	-----	(1)	----	-----	(1)	----	66	72	32	Do.
Chrysopsis mariana (L.) Nutt. (golden-aster)	Mar. 27	90	110	11	115	131	21	100	118	14	120	132	20	-----	(2)	----	86	143	28	86	178	44	98	172	24	Do.
Inula helenium L. (elecampane)	May 11	-----	(3)	...	16	40	30	-----	(1)	----	21	45	24	-----	(1)	----	-----	(1)	----	-----	(1)	----	22	51	33	Do.
Lacinaria graminifolia (Watt.) Kuntze (blazing-star)	May 19	18	44	12	18	42	12	-----	(1)	----	-----	(1)	----	-----	(1)	----	-----	(1)	----	-----	(1)	----	64	116	35	Do.
Lactuca spicata (Lam.) Hitch. (wild lettuce)	May 29	-----	87	65	-----	(1)	----	-----	(1)	----	-----	(1)	----	-----	(1)	----	-----	(1)	----	-----	(1)	----	-----	84	96	Indeterminate.
Silphium trifoliatum L. (rosinweed)	Apr. 18	89	107	38	89	110	56	68	90	56	68	89	70	65	89	83	65	89	76	54	79	54	54	78	57	Long day.

1 No test. 2 Injured. 3 Leafage only.

Under very short exposures the giant ragweed has shown a decided tendency to flower less promptly than the low ragweed. These rather appreciable differences of behavior would indicate that the low ragweed is a more pronounced short-day type of plant than the giant ragweed, or one may consider that the latter tends more to behave as a long-day plant. In fact, *A. trifida* comes into bloom and completes anthesis much earlier in the season than *A. elatior*, which may be in full anthesis long after *A. trifida* has ceased to liberate pollen. From their day-length requirements it is evident that these two species of ragweed are best adapted to middle latitudes rather than to those having extremely long summer days. On the basis of their day-length requirements for flowering and seed

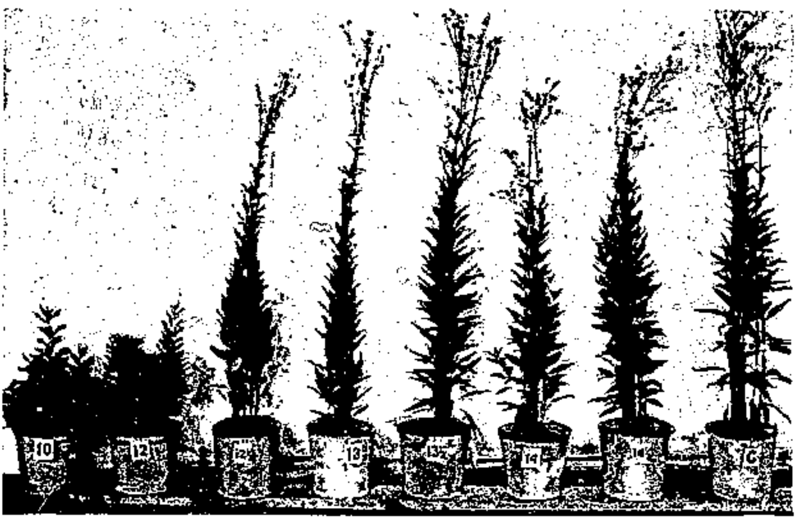

FIGURE 7.—*Silphium trifoliatum* L. Rosinweed, a native wild plant of the vicinity of Washington, D. C., with long-day tendencies. The plants flowered under different day lengths as follows: 10 and 12 hour, September 6; 12½ hour, August 15; 13 hour, July 22; 13½ hour, July 8; 14 hour, July 16; 14½ hour, July 18; full day (C), July 16. Tests began April 18; photographed August 22.

production before frost, these plants are not adapted to the high latitudes of Europe or to the British Isles. Actually, these ragweeds are practically unknown in Europe or the British Isles and are rarely listed in British or European floras as occurring at all. If they occur, they do not appear to persist, and European botanists have informed the writers that they are usually not able to flower and set seed before frost. An occasional plant of the species *Ambrosia elatior* has been found in Ireland, England, and the mainland of Europe, but *A. trifida* with its slightly longer critical day length has not been listed even as a casual.

Lacinaria graminifolia is a typical short-day plant, flowering quickly under 10 hours of daily light exposure, and also producing its largest corms in response to these short exposures. Senility came on quickly under the 10-hour conditions, whereas the plants enjoying the full length of day were still green and floriferous. The short exposures hastened the enlargement of the corm, flowering, and senility, and produced noticeably short stems.

Bidens bipinnata is a short-day type having a fairly high critical light period for flowering. If the short autumnal and winter days are supplemented from sunset until midnight by incandescent electric light, plants in the last stages of senility have been rejuvenated, and vegetative branches have developed that grew for an indefinite period without flowering.

Golden-aster (*Chrysopsis mariana*) has flowered under all lengths of day, but the shorter light periods have greatly hastened flowering. The plants were short and stocky under 10 hours of light and extremely productive of showy golden heads. A striking feature was the decumbent habit of the stout stems at the base. This decumbent habit was less evident in the 12-hour plants, and still less marked under the 12½-hour light period. The 13-hour plants and those enjoying longer daylight periods showed an erect stem growth.

So far as the tests have indicated, the flowering of elecampane is somewhat hastened by the shorter lengths of day, but leafage, alone, was developed under conditions of a 10-hour day. The plant may be rather indeterminate in its flowering responses, but it shows some indications of long-day behavior.

Wild lettuce (*Lactuca spicata*) has shown about the same flowering responses under 10 hours of daylight as under the full length of day, but in the latter test the height of the plants was greatly increased.

Various Ornamental Compositae

A number of the garden Compositae presented in table 8 tend to have day-length requirements extending through a very wide range, thus behaving as indeterminate types; several are typical long- or short-day plants.

Achillea ptarmica is a typical indeterminate plant in its flowering behavior, since it grows and flowers well throughout the entire range of light periods shown.

Ageratum is not clearly defined in its behavior. Although vigorous growth and flowering obtained under nearly all light periods, many sterile vegetative stems and few flower stems were produced with 10 hours of light daily, and the stems, although shorter, were loose, spreading, and much declined. As the daily light periods increased in length, there was a very noticeable increase in the flower-bearing stems and the stature of the plants. One strain shows the characteristics of a short-day plant.

Two strains of *Ammobium alatum* var. *grandiflorum* have been grown, and both behave as indeterminate types of plants. The 10-hour plants of one strain never flowered, but there was a progressive increase in the abundance of flowers on the longer light periods. The plants of the other strain flowered even under the short light periods of 10 or even 8 hours, but few flower stems were formed under these conditions. Beginning with 12 hours of light daily, many flower stems were formed and the plants were floriferous. It will be noted, also, that flowering was hastened by the longer light periods in one of the strains.

Anthemis tinctoria showed a poor growth throughout the series, perhaps due to extreme heat, but there was a gradual change from leafage alone, on the 10-hour period, with stem growth increasing in height as the light periods were increased. There was no flowering at any time. The plant is tentatively classed as a long-day plant

TABLE 8.—*Behavior of various ornamentals of the family Compositae in response to length of day*

Plants	Test began	Effect of daily light exposure of—																								Class
		10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day			
		Time required for—		Height	Time required for—		Height	Time required for—		Height	Time required for—		Height	Time required for—		Height	Time required for—		Height	Time required for—		Height	Time required for—		Height	
		Buds	Flowers		Buds	Flowers		Buds	Flowers		Buds	Flowers		Buds	Flowers		Buds	Flowers		Buds	Flowers		Buds	Flowers		
		Days	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	
Achillea ptarmica L.	May 10	46	62	24	39	56	22	40	64	22	50	74	24	51	68	25	20	48	22	42	56	23	30	46	20	Indeterminate.
Ageratum:																										
A. houstonianum Mill. (from Connecticut)	May 6	[1]	43	8	[1]	41	10	27	40	----	27	44	12	30	44	12	42	67	13	40	65	17	74	94	21	Short day.
A. houstonianum Mill. (Dreer Blue Perfection)	May 19	[2]	----	----	37	52	10	----	[3]	----	50	57	18	----	[3]	----	----	[3]	----	----	[3]	----	40	54	17	Long day(?).
Ammobium:																										
A. alatum R. Br. var. *grandiflorum*	May 28	57	67	24	28	48	24	----	[3]	----	29	48	20	----	[3]	----	----	[7]	----	----	[3]	----	23	35	29	Indeterminate
Do.	May 16	[2]	[4]	----	33	40	22	27	39	24	26	39	17	----	[3]	----	16	39	25	----	[4]	----	26	40	29	Do.
Anthemis tinctoria L. (Kelway's Anthemis)	May 29	----	[5]	----	----	[5]	----	----	[3]	----	----	[6]	----	----	[3]	----	----	[7]	----	----	[3]	----	----	[8]	----	Long day(?).
Arctotis:																										
A. fastuosa Jacq. (annual)	Apr. 26	46	53	13	46	56	16	----	[3]	----	50	94	20	54	71	34	58	71	27	56	74	37	46	58	21	Indeterminate.
A. stoechadifolia Berg. (African daisy)	May 21	11	26	9½	11	20	10	----	[3]	----	11	21	11	----	[3]	----	11	23	14	----	[3]	----	11	25	14	Do.
Bellis perennis L. (English daisy)	May 24	28	35	3	18	23	3	----	[3]	----	15	26	5	22	32	6	23	34	5	15	35	6	27	32	4	Do.
Brachycome iberidifolia Benth. (Swan River daisy)	May 14	15	30	11	15	30	9	17	42	12	26	38	12	29	43	16	17	31	13	----	[3]	----	15	30	10	Do.
Centaurea:																										
C. cyanus L. (double ruby red)	May 13	18	35	10	56	[4]	----	23	49	9	47	60	16	49	63	15	21	39	17	39	53	20	29	40	22	Do.
C. imperialis (bachelors-button)	do	11	29	4	21	42	9	16	32	16	16	32	11	----	[9]	----	26	33	8	18	35	20	22	36	19	Do.
C. moschata L. (sweet-sultan)	May 14	34	46	6	20	46	7	17	31	9	35	42	10	41	58	19	30	37	18	34	55	27	15	32	18	Do.

Coreopsis tinctoria Nutt.	May 31	76	92	42	41	56	34	----	(3)	----	48	66	37	48	66	37	31	45	44	----	(3)	----	31	45	34	Long day.
Dimorphotheca aurantiaca DC. (Cape-marigold)	May 27	----	(4)	----	----	(4)	----	7	21	12	14	25	13	35	49	13	15	30	15	24	33	12	14	24	11	Do.(?).
Emilia flammea Cass. (Cacalia)	May 13	16	27	20	16	28	20	16	28	17	16	28	19	16	28	20	16	32	23	16	33	23	16	31	25	Indeterminate.
Gilia capitata Dougl.	do	27	42	12	35	54	21	35	50	26	29	53	18	20	49	28	42	63	25	29	54	25	28	42	11	Do.
Heliopsis helianthoides var. *pitcheriana* Fletcher	Apr. 9	64	----	----	71	88	14	66	(10)	----	65	(10)	----	42	103	18	77	102	22	50	71	40	43	64	35	Long day.
Helipterum roseum Benth. (Dreer acroclinium, double-mixed)	May 16	57	(4)	----	60	68	26	----	(3)	----	68	86	48	----	(4)	----	----	(4)	----	----	(4)	----	30	39	27	Do.(?).
Scabiosa atropurpurea L. (large-flowering crimson)	May 22	62	85	16	----	(11)	----	----	(3)	----	66	90	34	----	(3)	----	49	73	36	----	(2)	----	32	59	33	Do.
Stokesia laevis Hill (Stoke's aster)	May 18	41	59	3½	----	(11)	----	----	(3)	----	109	----	----	----	(3)	----	83	110	11	98	120	17	103	----	----	Short day.
Tithonia:																										
T. rotundifolia (Mill.) Blake	May 14	18	33	42	18	35	61	18	39	47	18	35	47	25	46	57	25	50	46	56	60	63	53	81	66	Do.
Do	June 19	----	36	56	----	50	62		(4)	----	----	(3)	----		(3)	----	----	(5)	----		(4)			(12)		Do.
Tricholaena rosea Neis	May 14	20	31	3	17	26	7½	20	32	10	17	25	8	17	18	11	17	28	11	17	28	12	17	29	15	Indeterminate.
Ursinia anethoides (DC.) N. E. Br.	May 24	----	(2)	----	43	69	14	----	(2)	----	----	(4)	----	----	(3)	----	17	48	18	----	(3)	----	16	33	14	Long day.

[1] Budded previous to test: 10 hour on May 5, 12 hour May 4.
[2] No buds.
[3] No test.
[4] Died.
[5] Leafage only; died.
[6] Short stem growth.
[7] Good stem growth.
[8] Excellent growth.
[9] Rosette only; died.
[10] No flowers.
[11] Leafage only.
[12] Buds late in fall.

on the basis of this behavior. It is possible that this plant is best adapted to cooler climates and very long summer days, as it thrives in England and in the countries of northern Europe.

Arctotis stoechadifolia has been very floriferous under all light periods and behaves as an indeterminate (fig. 8). It shows somewhat delayed flowering on the longer light periods accompanied by increased stature.

English daisy (*Bellis perennis*) is a plant of indeterminate habit, as the tests indicate, but it seems ill-adapted to hot climates. This appears to be the correct interpretation, as its native home is in the far northern latitudes of England and the mainland of Europe, and it flowers nearly the whole year round.

Swan River daisy (*Brachycome iberidifolia*) and *Cacalia* also behave as true indeterminates, flowering abundantly under all light periods and with little or no delay as these are increased in length. *Brachycome* reached a senile condition and died somewhat sooner under the shortest light periods.

The several centaureas flowered fairly well on all the light periods, but made much better growth as the daily light periods increased in

FIGURE 8.—*Arctotis stoechadifolia* Berg. African daisy. A plant of indeterminate flowering habits within the limits of the present tests. The plants flowered under various day lengths as follows: 10 hour, June 16; 12 hour, June 10; 13 hour, June 11; 14 hour, June 13; full day (C), June 15. Indeterminate plants of this type are suitable for garden culture throughout a wide range into far northern latitudes. Tests began May 21; photographed June 30.

length. On the basis of their flowering responses, they have been placed in the indeterminate class: in their growth behavior they are favored by the longer days.

Coreopsis tinctoria has flowered under all light periods, but the 10-hour plants produced few flower stems and much leafage. With each succeeding increase in the light period, growth improved and the plants were noticeably more floriferous. These responses together with earlier flowering in response to the longer light periods would indicate a plant that is favored by long days.

Cape-marigold (*Dimorphotheca*) appears to be a weakly long-day plant in behavior and is likely to die or grow very poorly on very short days.

Gilia capitata and *Emilia flammea* have behaved as typical indeterminate plants flowering equally well under all conditions, but have attained somewhat greater stature on the longer light periods.

Heliopsis has shown the behavior of a typical long-day plant, scarcely budding or flowering on light periods of 13 hours or less. On the 10- and 12-hour periods the branches were lax, falling upon the ground, and abortive buds were formed. Flowering was poor on the 13½-hour period, but the branches had become erect. On all longer light periods and the full length of day, the plants were tall, strictly erect, and very floriferous. This plant in all respects is one of long-day requirements.

Helipterum roseum for the most part grew poorly under all light periods, but appears to be of long-day habit in some respects.

Sweet scabiosa is a typical long-day plant greatly favored by long light periods coupled with cool temperatures (fig. 9). Very few or no flower stems were found on the 10- and 12-hour periods, but a dense growth of leafage developed, and flowering was delayed. The plants have shown a similar failure to flower in the greenhouse in wintertime, except where artificial light was used to extend the illumination period, and the plants were then forced into vigorous growth and normal flowering.

Stokesia laevis has shown a rather pronounced short-day behavior.

The behavior of *Tithonia rotundifolia* is of some interest. This plant occurs in Central America where it grows under comparatively

FIGURE 9.—*Scabiosa atropurpurea* L. Large-flowering Crimson (Dreer), a long-day plant. The plants flowered under different day lengths as follows: 10 hour, August 15; 12 hour, never flowered; 13 hour, August 20; 14 hour, August 3; full day (C), July 20. The 10-, 12-, and 13-hour plants were characterized by dense leafage and poor flowering. Tests began May 22; photographed July 25.

short days. One of the strains shown in table 8 behaves as a typical short-day plant in higher latitudes and usually cannot flower in the vicinity of Washington before killing frosts occur in October or November. In response to 10 or 12 hours of light daily it has flowered readily in late July or early August. Under increased lengths of day it grows to great size as compared with those plants forced to flower under short days. Its rigid requirements for very short days to promote flowering make it a plant ill-adapted to regions much north of its native home.

Another strain, on the other hand, has a much longer critical light period, flowering well under all light periods employed, but with a delay of about 1 month on the longer light periods, together with increasing stature and greater longevity. The plants were almost or entirely dead on the 10- to 13½-hour light periods, inclusive, September 4, but were green and in full flower on the 14-, 14½-hour, and full length of day at this time. Delayed flowering on the longer light periods and reduced longevity on the short periods would indicate a plant of short-day tendency. This strain with its earlier flowering tenden-

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cies is much better adapted to become a garden ornamental in higher latitudes than those strains that must await very low critical lengths of day and therefore postpone flowering until very late in autumn.

Tricholaena rosea is of indeterminate habit, flowering about equally well under all light periods, and is characteristically of indeterminate habit, showing no delay in flowering on the longer light periods, and maintaining rather uniform stature throughout all the tests.

Ursinia anethoides shows long-day tendencies by a hastened flowering on the longer light periods, but the plant does not thrive in the warm summers of Washington, D. C., especially under artificially shortened light periods.

Goldenrods

The goldenrods presented in table 9 represent species ranging from the earliest to flower in the vicinity of Washington, *Solidago juncea*, to

Figure 10.—*Solidago altissima* L. A short-day goldenrod. The plants flowered under different day lengths as follows: 10 hour, June 25; 12 hour, July 6; 12½ hour, July 16; 13 hour, July 16; 13½ hour, July 20; 14 hour, August 24; 14½ hour, August 30; full day (C), September 18. Tests began April 5; photographed August 7.

some of the latest flowering species, *S. altissima*, *S. graminifolia*, and *S. nemoralis*.

Solidago altissima is one of the late goldenrods, its behavior being typically that of a pronounced short-day plant (fig. 10).

The species *Solidago cutleri* is a northern alpine found on Mount Washington, N. H., and in other high alpine districts from Maine to New York. It probably represents a long-day species, rather than one of short-day habit (fig. 11). It would appear that even the longest summer days in the vicinity of Washington, D. C., in combination with other conditions are too short to initiate flowering in this species. Vigorous leaf rosettes, only, were formed under all lengths of day.

Two strains of *S. fistulosa* were grown, one behaving as a typical short-day plant, the other flowering irregularly, so that its classification could not be made with certainty.

The species *S. graminifolia* behaves as a typical short-day plant, flowering as early as July 5 with 10 hours of light daily and showing delay of flowering together with increased stature for each half-hour increment in the daily light period until the full length of day was reached.

TABLE 9.—*Behavior of some native goldenrods (Solidago) in response to length of day*

Plants	Test began	Effect of daily light exposure of—																								Class
		10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day			
		Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			
		Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	
Solidago:		*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	
S. altissima L.	Apr. 5	57	81	23	67	92	22	75	102	25	77	102	32	79	106	33	67	141	56	109	147	51	130	166	62	Short day.
S. cutleri Fernald	Apr. 23	----	[1]	----	----	[1]	----	----	[1]	----	----	[1]	----	----	[1]	----	----	[1]	----	----	[1]	----	----	[1]	----	Long day.
S. fistulosa Mill. No. 1	Apr. 21	79	98	30	66	93	34	101	132	55	102	126	47	118	146	58	125	154	76	125	156	72	138	161	68	Short day.
S. fistulosa Mill. No. 2	do	----	[1]	----	----	[1]	----	----	[1]	----	----	[2]	----	----	[2]	----	----	[2]	----	133	157	32	----	[2]	----	(?).
S. graminifolia (L.) Salisb.	Apr. 5	63	91	23	76	99	21	75	106	31	71	111	25	81	119	28	88	142	42	88	147	46	95	170	43	Short day.
S. juncea Ait. No. 1	Apr. 23	70	91	38	77	90	27	79	101	31	73	96	38	79	100	39	79	105	41	82	108	37	81	119	43	Do.
S. juncea Ait. No. 2	do	56	74	16	59	77	18	59	78	26	70	93	14	60	89	33	59	85	21	59	93	32	80	119	39	Do.
S. nemoralis Ait.	Apr. 27	61	89	21	65	94	18	86	116	30	88	124	27	79	105	30	88	139	31	88	142	35	100	149	45	Do.
S. rugosa Mill. No. 1	Apr. 23	59	89	12	70	98	11	80	107	17	71	99	21	63	96	21	98	134	45	105	147	47	120	155	32	Do.
S. rugosa Mill. No. 2	do	39	63	15	54	74	13	63	88	17	51	78	18	65	96	19	58	129	36	113	141	42	120	155	46	Do.
S. sempervirens L.	do	31	50	10	36	55	12	----	[3]	----	41	62	12	41	60	17	43	67	20	49	76	36	79	137	38	Do.
S. ulmifolia Muhl.	do	39	73	25	45	73	22	69	88	14	49	77	19	58	82	32	57	88	36	85	108	30	67	[4] 114	36	Do.

[1] Leafy rosette.
[2] Leafy rosette and stems.
[3] No test made.
[4] In the field *Solidago juncea* is the earliest-flowering goldenrod, although in these tests *S. ulmifolia* was a few days earlier.

In the wild state nothing is more obvious than the successional flowering of the different species. *Solidago juncea* may even flower in June, and reaches its prime in mid-August, then declines, whereas *S. altissima* is then just developing its flower branches and tiny buds (fig. 12). The species *S. rugosa* is also one of the latest goldenrods to begin flowering. With the exception of *S. juncea*, which in some respects behaves as an indeterminate, the late-flowering goldenrods of the vicinity of Washington are more or less typical short-day plants

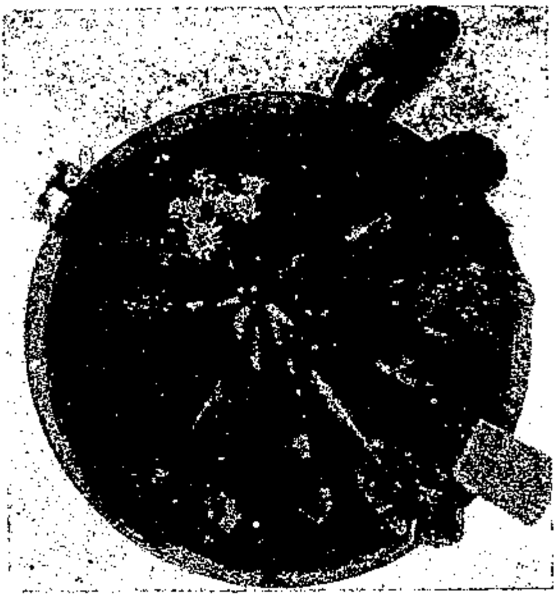

FIGURE 11.—*Solidago cutleri* Fernald. From Mount Washington. This species has never flowered at Washington, D. C., except as here shown. This plant flowered in the cool greenhouse February 14 when a rosette, the stem being practically absent. This appears to be a plant of long-day and cool temperature requirements. There is a tendency for all goldenrods to shorten their stems as the day length is reduced, even to such a degree that the inflorescence is almost stemless or is borne close to the rosette of leaves. (Photographed February 28.)

and show a greatly hastened flowering when grown under the shorter daily light exposures.

There are striking differences in the character of the inflorescence in response to the various light periods. The larger taller plants of the longer daily exposures produce a loose, open type of inflorescence more typical of the species as seen in a state of nature. The shorter lengths of day may produce a dense, compact type of inflorescence, which, in comparison with the typically developed form, is hardly recognizable as belonging to the species in question.

The extended flowering period of many of the goldenrods is also very striking. The earliest individuals of *Solidago juncea* appear in June, the latest in September or October. All the species of the Washington vicinity carry their flowering over a long period; even months may intervene between the first flowering individuals and the last to flower. It is evident that this long seasonal lag is due in part to the inclusion of many strains possessing slightly different critical levels of length of day at which flowering is initiated. Naturally, so long as flowering is not too late, so that seed production is not prevented by the advent of frost, a countless number of strains can arise and survive in any latitude, but as northern regions are approached, the species must trend toward the long-day behavior to survive, or at least the population will consist of a more uniform assemblage with a narrower range of day-length requirements nearer the critical favorable to successful seed production. A natural climatic selection will necessarily operate here to prevent seed production by the later stragglers, which might easily propagate in warmer latitudes.

These limitations would apply with particular force to such alpine species as *Solidago cutleri*, which must flower early to take advantage of the very cold and extremely short summers of alpine character that obtain upon Mount Washington. If this is a typical long-day

FIGURE 12.—*Solidago juncea* Ait. A native midsummer goldenrod of the vicinity of Washington, D. C. Flowering under various day lengths was as follows: 10 hours, July 23; 12 hours, July 31; 12½ hours, August 2; 13 hours, July 28; 13½ hours, August 1; 14 hours, August 6; 14½ hours, August 9; full day (C), August 20. This is the earliest flowering goldenrod in the Washington vicinity, some strains flowering in June. Tests began April 23; photographed August 7.

assemblage, as would appear, the species could not readily extend its range southward, even along the higher mountains, except through the survival and propagation by seed of strains capable of responding to shorter days. In such perennial types of hardy vegetative character, even though frost prevented seed production, the plants could long persist and propagate by offshoots; and such sterile plants appear to be present in many populations of the late Compositae.

Two strains of *Solidago juncea* were grown in the test. It will be seen from table 9 that strain No. 2 showed a tendency to flower earlier on nearly all the day lengths than strain No. 1.

S. nemoralis is perhaps the latest goldenrod of the Washington vicinity, coming into flower usually in August and persisting in favorable seasons into December, long after such species as *S. juncea*, *S. graminifolia*, and even *S. altissima* are past flowering.

Two strains of *S. rugosa* were grown, and from the behavior of these it is indicated that strain No. 1 is a faster-growing and somewhat earlier type in some respects, although both are short-day types.

The strain of *S. sempervirens* obtained from Connecticut flowers very quickly in response to shortened day lengths, and even in response to lengths of day as long as 14 and 14½ hours flowering occurred as early as June 29 and July 8, respectively (fig. 13). This particular goldenrod has shown itself to be the earliest flowering species in all tests where the length of day has been reduced below the full length of day of Washington, D. C., i. e., about 15 hours. This species has an exceedingly wide range, extending from the Gulf of St. Lawrence southward. It is obvious that in these far-northern latitudes early flowering in time to escape frost is a requisite. The species shows an early-flowering behavior even for the New England strain in the tests, and it is possible that still earlier strains exist near the northern limits of its range, i. e., showing the capacity to flower readily in response to still longer days than the strain tested.

Solidago ulmifolia is chiefly a woodland goldenrod, and the strain dealt with has been one of the earliest to flower in response to the full length of day. This species has shown no marked delay in flowering until lengths of day of 14 to 14½ hours have been reached.

FIGURE 13.—*Solidago sempervirens* L. A native goldenrod whose flowering is favored by long days, the flower stems in the short 10-hour day scarcely arising above the leafage. The plants flowered as follows: 10 hours, June 10; 12 hours, June 15; 12½ and 13 hours, June 16; 13½ hours, June 18; 14 hours, July 6; 14½ hours, July 7; full day (C), July 20. This goldenrod occurs from the Gulf of St. Lawrence southward and does not flower well when the days are too short. Tests began March 27; photographed June 30.

This behavior would indicate that the species is adapted to far-northern regions as well as lower latitudes and, as a matter of fact, it is found in Nova Scotia and ranges southward.

ASTERS

The data in table 10, showing the behavior of various asters (*Aster* and *Callistemma*) in response to different lengths of day, indicate that most of the native asters growing in the latitude of Washington, D. C., are members of the short-day class (figs. 14 and 15). This is apparent not only from their normal season of bloom, which comes in late summer or autumn, but from the fact that short daylight exposures of 10 or 12 hours induce flowering far in advance of the normal season of bloom. As the daylight exposures are lengthened, flowering becomes later, until daily exposures of 14 or 14½ hours cause a delay of many weeks, so that the plants flower no sooner than those exposed to the full length of day. This relationship is to be expected, if daily exposures of 14 and 14½ hours are beyond the critical period for flowering, as the 14½-hour and 14-hour plants must experience the full natural length of day after July 22 and August 7, respectively. It is of interest to observe that the 14- and 14½-hour plants have usually flowered at about the same time as the plants experiencing the full length of day. This is especially well illustrated in the behavior of *A. cordifolius* and *A. undulatus* (table 10).

The various species of wild aster show marked differences of response, both to the reduced hours of illumination and to the full length of day, *Aster novæ-angliae* in the tests being much earlier than *A.*

FIGURE 14.—*Aster pilosus* var. *demotus* Blake. A native autumn-flowering aster. With different day lengths the plants flowered as follows: 10 hours, June 25; 12 hours, July 9; 12½ hours, July 13; 13 hours, July 9; 13½ hours, July 21; 14 hours, September 15; 14½ hours, September 5; full day (C), September 17. This aster, like nearly all the native asters of the Washington vicinity, flowers in autumn because of the shortened days. Tests began April 5; photographed August 7.

cordifolius. Nature has produced comparatively few wild long-day asters or other composites in the latitude of Washington, D. C. Practically none of the true asters of the region flower before late August or September. The species of the genus *Erigeron* and the white-topped

FIGURE 15.—*Aster lateriflorus* (L.) Britt. Native. The plants flowered under different day lengths as follows: 10 hours, June 23; 12 hours, July 1; 12½ hours, July 12; 13 hours, July 5; 13½ hours, July 12; 14 hours, September 18; 14½ hours, September 23; full day (C), September 30. A typical short-day plant awaiting the short days of autumn to flower, as is true of most of the native wild asters. Tests began May 19; photographed September 8.

asters of the genus *Sericocarpus* are exceptions in being indeterminate or long-day types of plants.

It has been possible to cause some of the fall asters to flower twice in a season. *Aster linariifolius*, after flowering in June in response to a short day, was exposed to the full length of day, producing new vegetative shoots that flowered at the normal time in early September as the days naturally shortened.

TABLE 10.—*Behavior of some native wild asters (Aster) and cultivated forms of the China-aster (Callistemma) in response to length of day*

Plants	Test began [1]	Effect of daily light exposure of— 10 hours: Time required for— Buds	10 hours: Time required for— Flowers	10 hours: Height	12 hours: Time required for— Buds	12 hours: Flowers	12 hours: Height	12½ hours: Time required for— Buds	12½ hours: Flowers	12½ hours: Height	13 hours: Time required for— Buds	13 hours: Flowers	13 hours: Height	13½ hours: Time required for— Buds	13½ hours: Flowers	13½ hours: Height	14 hours: Time required for— Buds	14 hours: Flowers	14 hours: Height	14½ hours: Time required for— Buds	14½ hours: Flowers	14½ hours: Height	Full length of day: Time required for— Buds	Full length of day: Flowers	Full length of day: Height	Class
Aster:																										
		Days	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	
A. commutatus T. and G. (Gray) (western native)	Mar. 27	59	73	7	62	78	9	----	(2)	--	71	89	12	77	90	17	79	96	17	----	(2)	----	139	153	22	Short day.
A. cordifolius L. (native)	do	79	102	20	93	123	20	97	139	18	90	125	22	----	(2)		156	188	18	163	189	18	174	197	28	Do.
A. ericoides L. (native)	do	72	90	20	90	104	28	84	103	31	90	104	34	93	116	29	142	172	49	141	162	43	155	174	40	Do.
A. lateriflorus (L.) Britt. (native)	do	83	97	15	93	118	13	95	149	27	83	100	30	92	112	29	149	181	33	----	(2)	---	162	185	35	Do.
A. linariifolius L. (native)	do	66	86	19	88	103	14	71	93	10	74	94	19	77	113	19	150	181	23	----	(2)	----	163	187	24	Do.
A. novae-angliae L. (native)	do	56	71	8	63	74	11	69	86	19	69	86	21	66	84	15	73	95	25	90	127	23	141	162	---	Do.
A. paniculatus Lam. (native)	do	69	85	35	72	90	36	86	100	48	76	93	48	84	104	47	118	143	62	150	174	72	154	181	60	Do.
A. tataricus L. (native to China)	Apr. 4	92	119	35	----	(3)	----	----	(3)	---	104	132	31	112	147	53	----	(3)	..	153	186	64	---	(3)	---	Do.
A. tradescanti L. (native)	Mar. 27	91	107	25	76	93	17	91	100	19	93	112	19	125	137	14	139	167	29	151	168	56	157	167	30	Do.
A. undulatus L. (native)	do	76	98	34	86	106	25	97	123	41	78	90	28	118	134	41	161	178	43	161	180	68	162	181	42	Do.
Callistemma:																										
C. chinense (L.) Skeels (China-aster, Sensation variety)	May 10	54	(4)	----	57	82	16	56	81	17	49	72	22	65	96	25	50	81	29	49	76	26	56	93	32	Indeterminate.
C. chinense (L.) Skeels (China-aster. Heart of France variety)	May 13	29	50	10	29	53	12	38	59	15	29	51	12	35	59	18	35	60	20	42	75	28	47	74	27	Do.
C. chinense (L.) Skeels (China-aster, Giant California Sunshine variety)	May 10	75	103	17	50	93	26	67	105	31	62	100	29	54	102	38	71	105	...	50	95	32	58	100	34	Do.

[1] 10- and 12-hour tests began on this date. Tests involving daily light exposures longer than 12 hours began on the dates when the length of day from sunrise to sunset had reached these values. (See table 2.) Until these tests began, plants received normal day length.

[2] No test made.

[3] Rosette formed.

[4] Bloomed sometime in July; exact date not known.

Aster tataricus, although obviously flowering quickly in response to short daily light exposures, is somewhat erratic in its flowering behavior, often making a heavy growth of basal leafage without the stem elongation that leads to flowering. This, however, is also true of some of the native sorts, such as *A. macrophyllus*, common in the more mountainous parts of Virginia.

The China-asters representing the Old World species (*Callistemma chinensis*) appear to be indeterminate in relation to length of day, within the range here covered, and for that reason are early-flowering sorts suitable for growing in far-northern regions. It is probable that the original home of the species is in rather high latitudes.

Helianthus, Rudbeckia, and Echinacea

As shown by delayed flowering and decreased stature under the 10-hour daily light exposure, *Echinacea purpurea*, one of the cone-

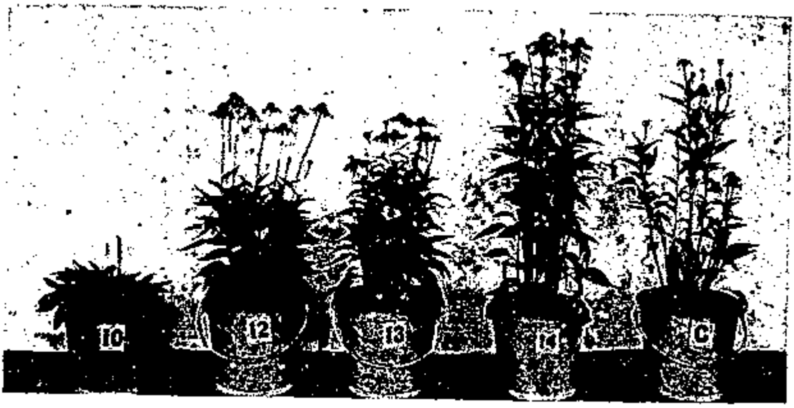

Figure 16.—*Echinacea purpurea* (L.) Moench. Purple coneflower (Dreer). A long-day plant with a low critical length of day unfavorable to flowering. The plants flowered as follows: 10 hour, July 19 (one flower stem); 12 hour, June 19; 13 hour, June 20; 14 hour, June 15; full day (C), June 15. Tests began March 27; photographed June 30.

flowers (table 11), is a long-day plant (fig. 16). Although it is indicated that this species finds long days more favorable to flowering, it extends its flowering well down into the shorter daylight exposures, in marked contrast to the species *Rudbeckia nitida* and *R. laciniata*. The latter have always produced only dense masses of leafage in response to short photoperiods.

The sunflowers (*Helianthus*) in the tests presented in table 11 include fairly typical long-day, short-day, and indeterminate types of plants. Practically all are native or grow wild in the eastern section of the United States, and the majority occur in the flora of the District of Columbia area.

Helianthus laevigatus is native to the high Alleghenies of Virginia and southward, the material in the tests coming from Big Bald Knob, in Augusta County, Va., at about 4,300 feet. The species *H. tuberosus* is characteristically tuber bearing and in the tests has flowered rather irregularly for unknown reasons. Tuber formation is intimately

TABLE 11.—*Behavior of some species of Helianthus, Rudbeckia, and Echinacea in response to length of day*

Plants	Test began	Effect of daily light exposure of—																								Class
		10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day			
		Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			
		Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	Buds	Flowers	Height	
		Days	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	
Echinacea purpurea (L.) Moench	Mar. 27	100	115	9	54	84	26	----	(1)	----	52	85	23	----	(1)		45	80	34	----	(1)	----	42	78	30	Long day.
Helianthus:																										
H. angustifolius L.	May 18	24	43	34	29	54	41	38	76	42	29	66	45	54	104	62	76	123	90	76	129	89	109	143	72	Short day.
H. divaricatus L.	Apr. 13	56	87	31	62	93	22	52	81	37	62	89	29	48	76	40	45	73	46	51	80	32	51	87	29	Indeterminate.
H. giganteus L.	Apr. 5	95	120	42	118	137	28	131	141	93	112	131	57	117	138	42	111	140	56	99	127	66	95	137	63	Do.
H. laevigatus T. and G.	Apr. 11	61	95	48	64	96	52	61	96	63	61	111	58	61	102	60	61	98	54	81	121	84	97	102	52	Do.
H. maximiliani Schrad.	Mar. 27	----	(2)	----	----	(2)	----	----	(2)	----	----	(2)	----	80	91	21		(2)	----	64	84	57	80	105	40	Long day.
H. strumosus L.	do.	84	110	66	89	110	72	----	(1)	----	79	103	67	83	106	74	70	91	52	----	(1)	----	71	110	66	Indeterminate.
H. tuberosus L. (Jerusalem - artichoke)	Apr. 5	----	(3)	----	----	(4)	----	----	(5)	----	----	(6)	----	----	(6)	----	88	[7] 122	19	----	(8)	----	----	(9)	----	Do.
Rudbeckia:																										
R. hirta L. (coneflower)	May 7	32	42	4	40	57	2½	32	53	3	32	55	8	32	60	16	27	53	22	29	53	24	32	57	27	Do.
R. laciniata L. (goldenglow)	Apr. 9	----	(10)	----	----	(10)	----	----	(10)	----	----	(10)	----	----	(11)	----	----	(11)	----	77	98	32	75	100	45	Long day.
R. newmani Loud; No. 1	Apr. 23	46	74	14	46	74	20	43	74	22½	44	77	24	46	74	24	46	76	31	46	76	31	46	81	20	Indeterminate.
R. newmani No. 2	May 7	----	(10)	----	102	(12)	----	69	98	21	60	89	10½	55	90	24	49	82	25	42	79	21	42	82	24	Long day.
R. nitida Nutt.	Mar. 27	----	(13)	----	----	(13)	----	----	(13)	----	----	(13)	----	----	(13)	----	----	(13)	----	84	110	32	91	131	48	Do.

[1] No test.
[2] Only sterile stems.
[3] Stems sterile; full-grown tubers Aug. 8.
[4] Buds Aug. 12; full-grown tubers Aug. 8.
[5] Stems sterile; no tubers Aug. 8.
[6] Stems sterile; tubers developed Aug. 8.
[7] No tubers Aug. 22.
[8] Stems sterile; no tubers Aug. 22.
[9] Stems sterile; tubers enlarging Sept. 20.
[10] Leafage only.
[11] Slight stem elongation.
[12] Mostly leafage.
[13] Stems sterile.

associated with the length of the daily light period, as the tests indicate. If classified on the basis of tuber formation, as has been done by some authors, it would be considered to be a short-day type.

Helianthus angustifolius behaves as a typical short-day plant, flowering in 43 days with 10 hours of light daily and requiring longer periods of time to flower with increased daily light periods. The species *H. divaricatus*, *H. giganteus*, *H. laevigatus*, *and H. strumosus* behave as typical indeterminate types of plants, showing no marked differences in time of flowering in response to the various light periods and no great differences in height. *H. maximiliani* appears to be a typical long-day type of plant that ceases to flower when the daylight periods are too short.

The common sunflower (*Helianthus annuus*) was not grown in the present tests, but when planted in the field at intervals throughout the season appeared to be an indeterminate plant in its flowering behavior, as shown in table 12.

The species of *Rudbeckia* in the tests, for the most part, are long-day plants. The two different strains of *R. newmani* that were grown differ somewhat in their day-length requirements, No. 1 being indeterminate in its flowering behavior and No. 2 being a long-day type.

TABLE 12.—*Behavior of the common sunflower (Helianthus annuus) when planted in the field*

Date of germination	Flowers		Height	Average length of day until flowering	
	Date	Days			
		Number	*Inches*	*Hours*	*Minutes*
June 20	Aug. 10	51		14	14
July 5	do	45		14	13
July 19	Sept. 6	49	66	13	43
Aug. 2	Sept. 19	48	60	13	15
Aug. 18	Oct. 2	45	50	12	41
Sept. 2	Oct. 24	52	42	11	56

Rudbeckia hirta resembles *Echinacea purpurea* in its flowering behavior, producing few flowers, which are borne on very short flower stems under the shorter exposures. Usually a dense basal leafage developed until the 13½-hour exposure was reached. At this and longer exposures, basal leafage was sparse or lacking, but flowers were produced in great abundance, with many flowering stems. On the 10-hour day the flower stems were so short that the flowers were almost buried within the dense leafage. The species *Rudbeckia nitida* and *R. laciniata* have always shown a very pronounced long-day behavior, producing only a mass of leafage or, at the most, a slight stem elongation without flowering when the daily light exposures have been but slightly reduced below the full day of Washington, D. C. (fig. 17). *Rudbeckia newmani* strain No. 1 shows an indeterminate flowering, but strain No. 2 of the same species behaves as a long-day plant (fig. 18).

GRASSES

Most of the species of grass presented in table 13 appear to flower readily under practically all the lengths of day under which they were grown, with the exception of *Agrostis nebulosa* and *Andropogon virginicus;* these have produced leafage alone under the shorter lengths of day. The species *A. nebulosa* does not appear to thrive in the dormant condition enforced by the shorter lengths of day and appears to succumb to the high summer temperatures that prevail near Washington, D. C.

Andropogon virginicus has shown dominantly the behavior of a short-day type of plant, but flowering appears to be inhibited when

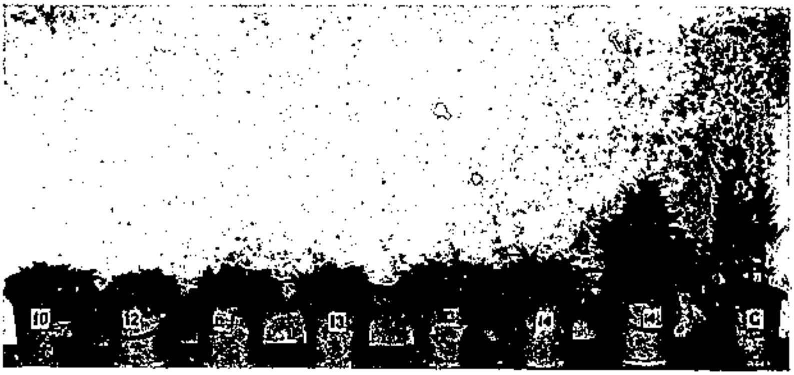

FIGURE 17.—*Rudbeckia laciniata* L. Goldenglow. Some strains at least are typical long-day plants with a very high critical lower limit favorable to flowering. The response to different day lengths was as follows: 10-, 12-, 12½-, and 13-hour plants remained rosettes with no stem elongation; 13½- and 14-hour plants produced some stem elongation without flowering; 14½-hour plants flowered July 16; full-day plants (C), flowered July 18. Tests began April 9; photographed July 25.

only 10 hours of light each day are experienced, and flowering is also delayed by lengths of day exceeding 13½ hours. A light period of 10 hours produced dense leafage strikingly upright in its habit of growth.

FIGURE 18.—*Rudbeckia newmani* Loud. A long-day species, with the critical limit at which flowering ceases below 12 hours. The plants flowered under various day lengths as follows: 10-hour day, remained a rosette; 12 hour, July 17; 12½ hour, July 15; 13 hour, July 17; 13½ hour, July 15; 14 hour, July 11; 14½ hour, July 15; full day (C), July 22.

The plants flowered most quickly when light periods of 12, 12½, and 13½ hours each day were experienced, anthesis taking place around August 20. Light periods of 14 and 14½ hours delayed heading and anthesis, although the plants in these tests flowered earlier than the controls receiving the full length of day. The latter, however, experience not only an inconstant length of day but also light periods that may not be favorable to flowering in the sequence of the seasonal changes before and after the summer solstice. In the field this grass

TABLE 13.—*Behavior of some native and ornamental species of grasses in response to length of day*

Plants and source	Test began	Effect of daily light exposure of—																								Class
		10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day			
		Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			Time required for—			
		Heads	First open florets	Height	Heads	First open florets	Height	Heads	First open florets	Height	Heads	First open florets	Height	Heads	First open florets	Height	Heads	First open florets	Height	Heads	First open florets	Height	Heads	First open florets	Height	
		Days	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	
Agrostis nebulosa Boiss. and Reut. (cloudgrass, Spain)	May 14	(1)	(2)	----	(1)	(2)	----	(1)	(2)	----	49	58	10	48	58	13	37	45	11	35	41	16	34	48	11	Long day.
Andropogon virginicus L. (native broomsedge)	May 29	(3)	----	----	78	80	31	81	86	27	(4)	----	----	78	83	37	90	99	52	108	114	49	118	132	38	Short day.
Calamagrostis cinnoides (Muhl.) Barton (native [5] reedgrass)	Mar. 30	67	95	39	58	76	41	63	88	42½	70	98	35	63	84	41	57	84	46	67	91	45	60	84	37	Indeterminate.
Coix lacryma-jobi L. (jobs-tears, India; tropical)	May 13	----	35	11	----	24	11	----	24	10	----	23	8½	----	19	7	----	19	7	----	26	10	----	23	8	Do.
Panicum miliaceum L. (German millet)	June 1	28	----	22	30	----	30	31	----	25	31	----	32	38	----	36	44	----	38	45	----	47	52	----	47	Do.(?).
Pennisetum:																										
P. alopecuroides (L.) Spreng. (China)	May 26	48	55	19	48	56	26	----	(6)	----	56	64	28	----	(6)	----	48	55	35	----	(6)	----	70	83	39	Short day (?).
P. ruppelii Steud. (fountain grass, Abyssinia)	May 25	42	49	24	39	46	23	----	(6)	----	39	46	27	----	(6)	----	50	56	38	----	(6)	----	46	52	28	Indeterminate.
P. villosum R. Br. (feathertop, Ethiopia)	May 21	22	29	24½	22	29	18	----	(6)	----	28	66	26	----	(6)	----	34	48	29	----	(6)	----	32	43	19	Do.
Triodia flava (L.) Smyth, (purpletop)	May 20	29	38	26	39	44	25	39	46	37	42	47	30	43	51	45	50	56	25	69	87	51	92	103	42	Short day.
Tripsacum dactyloides L. (eastern gama-grass)	Mar. 31	63	72	64	65	75	56	68	75	45	68	75	67	68	76	58	81	89	56	82	89	60	82	89	65	Do.

[1] No heads appeared.
[2] Plant died.
[3] Upright leafage only.
[4] Leafage only.
[5] From Big Bald Knob, Augusta County, Va.
[6] No test.

begins to flower in August or September when the seasonal length of day has fallen to about 13 hours or less. In its natural distribution, broomsedge does not extend farther north than Massachusetts and New York, and this may be because the days are too long for successful flowering before frost at more northerly latitudes.

German millet (*Panicum miliaceum*) is rather indifferent in its flowering responses to the different daily light periods but is somewhat hastened by the shorter periods. The stature of the plants at flowering is very noticeably affected by the light period, increasing as the daily light periods are increased. The exact date of flowering in the tests was not determined, but followed a few days after the date of heading.

The species *Pennisetum villosum* and *P. ruppelii* are native to Ethiopia, where the days are normally short, but, being indifferent in

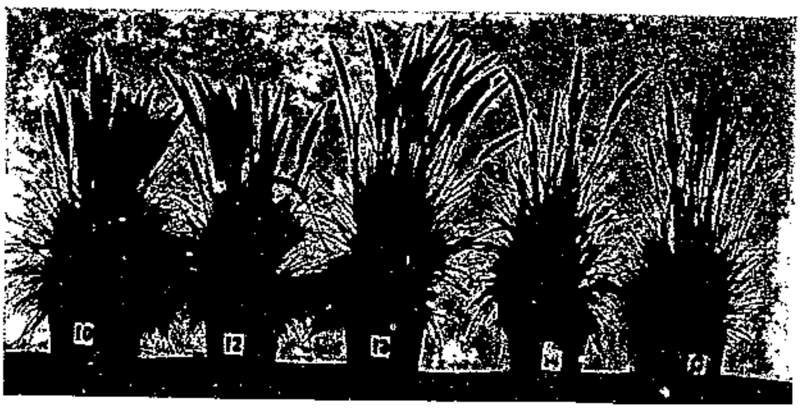

FIGURE 19.—*Pennisetum rupellii* Steud. (Dreer). An indeterminate plant flowering equally quickly under wide ranges of day length. Time of flowering under different day lengths was as follows: 10 hours, July 13; 12 and 13 hours, July 10; 14 hours, July 20; full day (C), July 16. Plants of this habit with respect to day length are adapted to wide ranges in latitude as a garden ornamental. Tests began May 25; photographed July 25.

their day-length requirements, these have found favor as garden ornamentals in the high latitudes of temperate regions, and *P. ruppelii* has even escaped sparingly in Michigan and elsewhere (fig. 19). It is readily apparent that tropical annuals with indifferent day-length requirements are well fitted to become useful plants during the summer season at almost any high latitude.

The grass *Triodia flava* flowered under all the tests, but, as the light periods increased, flowering was noticeably delayed up to the full length of day. This would indicate that prompt flowering is favored by a shortening day rather than by an increasing day. On the other hand, jobs-tears and all the species of *Pennisetum* appear to be little influenced by any of the light periods, and these grasses are truly indeterminate types. The species *Calamagrostis cinnoides*, taken on the top of Big Bald Knob, Augusta County, Va., at an altitude of more than 4,000 feet, appears to be of indeterminate habit.

Leguminosae and Labiateae

Among the legumes whose behavior is shown in table 14, wild-indigo (*Baptisia tinctoria*) and hyacinth-bean (*Dolichos lablab*) appear to be indeterminate types as judged by their behavior toward increased light durations and the full length of day of the Washington latitude (fig. 20). It will be noted that there has been no obvious delay in the time of flowering in response to the longest days of this latitude. A final conclusion cannot be reached, however, until the plants have been subjected to greatly increased lengths of day approaching continuous illumination to determine if a very high critical length of day for flowering exists.

The flowering behavior of the hogpeanut is highly specialized with respect to length of day. Although flowers are produced in response to all lengths of day, there is marked delay under the longer day lengths, and differences of floral morphology are definitely related to differences in length of day.

Glottidium vesicarium is a typical short-day plant, flowering on a 10-hour day about 1 month after the tests began. Flowering was delayed until October 6, or 142 days, when exposed to full daylight.

Phaseolus multiflorus may prove to be a long-day plant, as the short light periods of 10 and 12 hours were characterized by poor flowering; the plants appeared more floriferous as the light periods increased in length. The Madagascar lima bean (*P. lunatus*) is strictly a short-day plant, having a critical length of day between 13 and 13½ hours. The Biloxi variety of soybean is a typical short-day plant. The Peking variety also is a short-day plant, flowering quickly and dying under all lengths of day up to 14½ hours, the critical length of day for flowering being not far from the maximum length of day of the Washington vicinity, which is 14 hours and 54 minutes.

Koellia incana was not affected by the photoperiod, and it has been classed as an indeterminate type.

Beebalm (*Monarda didyma*) shows more or less of the typical behavior expected of long-day plants; that is, sterile stems and retarded flowering as the light periods are decreased in length.

Lallamantia iberica, two strains of which were obtained from the Division of Drug and Related Plants, Bureau of Plant Industry, has not shown particularly pronounced changes in time of flowering under the conditions of the tests ranging from 10 hours of daylight to the full length of day. So far as could be determined, however, the longer days appeared more favorable to flowering. It is possible that flowering is not much affected except by lengths of day in excess of the full length of day of the Washington latitude. From the data at hand it is indicated that little would be gained by growing the plants farther south, since shortened days have had little effect in increasing the stature or changing the flowering time of the plants. There is some reason to believe that this plant would become larger and more floriferous in more northern latitudes.

Nepeta mussini, an ornamental garden plant, has shown more or less of the behavior of a typical long-day plant, flowering more profusely as the days were increased in length.

Perilla frutescens and its varieties, with few exceptions, are very striking short-day types, as indicated in the tests (fig. 21). A number of forms have been included, among these being one found growing

TABLE 14.—*Behavior of some members of the pulse family (Leguminosae) and mint family (Labiateae) in response to length of day*

Family and plants	Test began	Effect of daily light exposure of— 10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day			Class
		Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	Time required for— Buds	Time required for— Flowers	Height	
Leguminosae:																										
Baptisia tinctoria (L.) R. Br. (wild-indigo, native)	Mar. 27	*Days* 56	*Days* 82	*In.* 14	*Days* 56	*Days* 80	*In.* 20	*Days* 56	*Days* 79	*In.* 18	*Days* 56	*Days* 82	*In.* 17	*Days* 56	*Days* 83	*In.* 17	*Days* 56	*Days* 83	*In.* 15	*Days* 56	*Days* 83	*In.* 22	*Days* 59	*Days* 86	*In.* 17	Indeterminate.
Dolichos lablab L. (hyacinth-bean)	May 15	39	52	60	34	45	46	34	45	50	41	54	60	45	55	60	45	54	60	49	59	60	52	59	28	Do.
Falcata comosa (L.) Kuntze (hogpeanut)	May 6	-----	35	---	-----	35	---	-----	(1)	---	-----	37	---	-----	48	---	-----	(1)	---	-----	(1)	---	---	98	---	Short day.
Glottidium vesicarium (Jor.) Desv. (native, south)	May 17	20	33	28	40	51	44	44	63	65	42	61	55	72	93	87	115	132	74	117	127	70	118	142	68	Do.
Phaseolus (Lima bean):																										
P. lunatus L. (from Madagascar)	June 11	----	5)	60	-----	48	55	-----	(1)	---	-----	47	56	-----	85	52	-----	(1)	---	-----	(1)	---	-----	85	75	Do.
P. multiflorus Willd. (scarlet runner)	May 21	13	53	26	14	22	21	14	21	31	14	22	31	14	25	46	14	28	66	20	28	46	14	32	56	Indeterminate.
Soja max (L.) Piper (soybean):																										
Biloxi variety	May 25	20	23	9	21	27	14	24	27	18	25	31	16	34	37	19	42	48	27	50	60	30	81	90	38	Short day.
Peking variety	do	15	20	5	15	20	7	15	20	7	17	21	7	17	22	9	21	23	7	20	23	8	59	63	23	Do.
Labiateae:																										
Koellia incana (L.) Kuntze (mountain-mint, native)	Apr. 20	-----	(2)	----	60	78	24	60	74	25	-----	(2)	----	54	74	30	61	78	29	-----	(1)	----	56	78	21	Indeterminate.
Lallamantia iberica (Bieb.) Fisch. and May:																										
P. I. 114389	May 13	33	46	15	19	27	9	28	33	13½	20	26	13	19	26	10	19	25	10	25	28	13	19	25	7½	Long day.
P. I. 114610	do	29	39	11	19	33	13	20	27	12	19	25	8	23	26	9	25	33	15	19	46	9	22	26	12	Indeterminate.
Monarda didyma L. (beebalm, native)	Apr. 10	-----	(3)	----	-----	(3)	----	----	(1)	----	68	81	24	----	(1)	----	----	(1)	----	----	(1)	----	61	74	26	Long day.
Nepeta mussini Spreng.	Apr. 12	-----	(4)	----	46	50	9	32	39	7	23	36	10	22	38	9	16	32	11	-----	(1)	----	16	32	12	Indeterminate.

Perilla:																										
P. frutescens (L.) Britt.[5]	May 17	25	39	22	37	47	27	39	58	30	39	50	25	49	70	38	53	83	41	62	96	47	93	114	50	Short day.
P. frutescens (L.) Britt. (green leaved, from Arlington Farm)	May 11, 1937	10	15	8	14	16	7	14	26	8	14	21	9	14	21	12	14	21	10	14	21	7	14	22	12	Do.
P. frutescens (L.) Britt. (red leaved, from Japan)	May 12, 1937	20	30	7	20	28	14	24	33	20	26	40	21	30	55	28	51	90	38	40	120	45	106	132	65	Do.
P. frutescens var. *nankinensis* (Decaisne) Bailey (red leaved, from Japan)	May 7, 1936	14	22	10½	14	22	11	15	26	13	15	26	13	13	26	13	20	37	16	51	92	52	113	130	52	Do.
P. frutescens var. *nankinensis* (red leaved, from Japan)	May 13, 1937	19	25	13	19	27	21	23	32	21	25	42	22	26	43	25	46	76	41	60*	105	52	106	133	62	Do.
P. frutescens var. *nankinensis* (Decaisne) Bailey (green leaved, from France)	May 7, 1936	(6)	25	16	13	[illegible]	18	13	37	18	12	26	16	28	30	29	27	39	22½	39	43	28	123	130	65	Do.
P. frutescens var. *nankinensis* (Decaisne) Bailey (green leaved, from France)	May 13, 1937	20	27	11	20	30	14	25	34	18	32	42	17	39	54	28	46	65	25	54	84	34½	98	113	42	Do.
Salvia:																										
S. hispanica L. (Chia)	May 17	28	42	37	28	42	35	28	42	41	31	50	4	50	92	64	98	144	72	107	147	82	107	147	85	Do.
S. sclarea L.	Mar. 27	----	(7)	----	----	(8)	----	----	(8)	----	----	(3)	----	----	(3)	----	67	83	19	----	(1)	----	63	72	29	Long day.
S. splendens Ker. (scarlet sage)	May 16	22	30	8	22	34	9	----	(1)	----	22	29	9	23	31	10	23	31	11	23	34	9	35	48	15	Indeterminate.

1 No test made.
2 Only sterile stems developed.
3 Stem elongation only.
4 A few flowers only.
5 Seed obtained from wild plants found on the banks along the upper Potomac; seed of Lallamantia, *Salvia sclarea*, *S. hispanica*, and all seed of *Perilla* and its varieties obtained from the Division of Drug and Related Plants, U. S. Department of Agriculture.
6 Budded May 7, the day the tests began.
7 Leafage only developed.
8 Slight stem elongation only.

spontaneously in the vicinity of Washington, for the species has established itself in many localities since its introduction into North

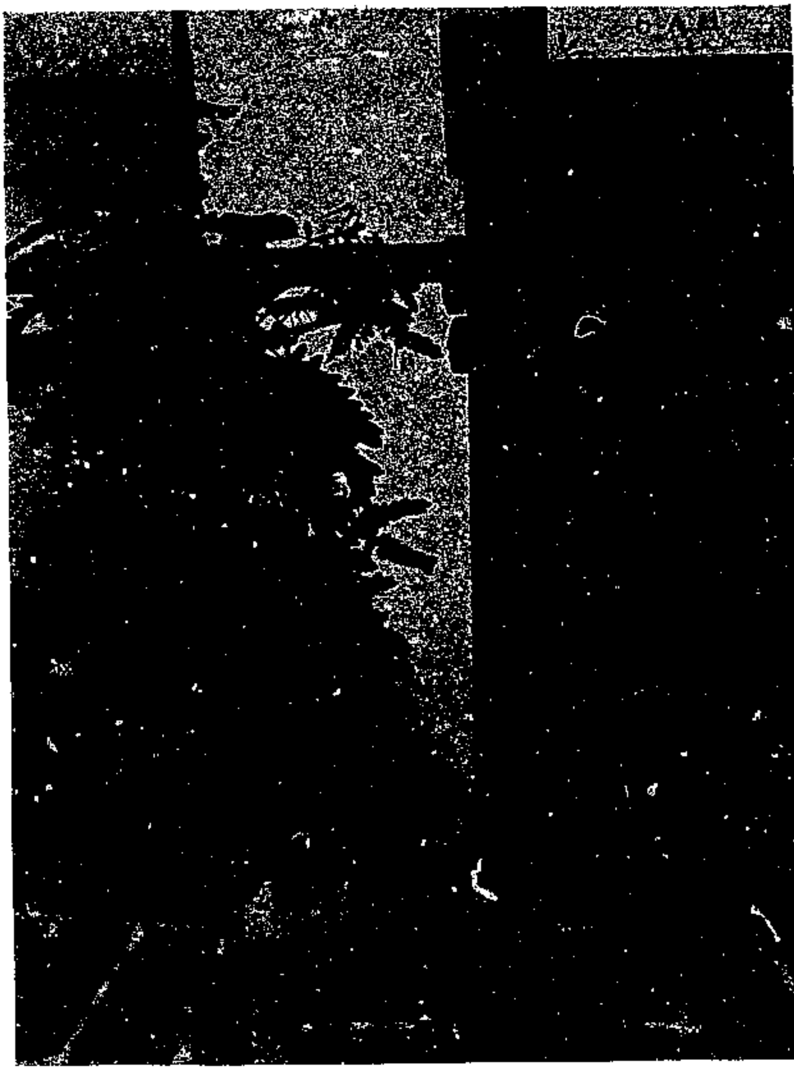

FIGURE 20.—*Cassia marilandica* L. Wild senna. A native long-day legume that has never flowered when the days have been much reduced in length. In the test, the same rootstock is so arranged that the portion in the case receives only 10 hours of daylight each day whereas that outside receives the full length of day. Only a few short, weak shoots developed under 10 hours of daylight, the leaves of which ultimately assumed the normal yellow autumnal coloration. These shoots died later, apparently due to an early enforced dormancy. Outside portion experiencing the full day flowered August 8 when 40 inches high. Tests began April 9; photographed August 24.

America. This form has behaved as a typical short-day type, the plants experiencing the full-day flowering 100 days later than those receiving 10 hours of daylight each day.

Several commercial strains furnished by the Division of Drug and Related Plants have been studied for their day-length requirement. When sown in May under the various lengths of day all these strains have shown the behavior of typical autumn-flowering short-day plants, withholding flowering usually until well into September.

The behavior of the green-leaved Arlington farm strain, which is also known to possess this late-flowering habit, would seem to be anomalous, but it is known that the seeds were sown in the greenhouse too early in the spring prior to the beginning of the test and were influenced by the shorter days, so that flowering on all the tests was hastened. These strains usually have a high and narrow critical length of day for flowering between 14 and 14½ hours or slightly longer. It will be noted that when 14 hours has been reached an increase of only one-half hour delayed flowering by nearly 2 months, with an attendant great increase in stature of the sort known as Red Japan,

FIGURE 21.—*Perilla frutescens* (L.) Britt. Red Japan. A short-day plant not adapted to the long days of northern latitudes. The plants flowered as follows: 10 hour, May 29; 12 hour, May 29; 12½ hour, 13 hour, and 13½ hour, June 2; 14 hour, June 13; 14½ hour, August 27; full day (C), September 14. Tests began May 7; photographed June 30.

so called because of its deep-red leaves. The controls experiencing a still longer day flowered just 3 months later.

The late-flowering behavior of these plants in the field at Washington, coupled with large stature and the fact of hastened flowering in response to shortened daily light periods, indicates that some plantings made in the latitude of Washington may be rather near the critical length of day for successful flowering and seed production before frost. In warm frost-free autumns seed production might occur, even somewhat farther north, but under such conditions the hazards of seasons with early frost would be expected sooner or later. At lower latitudes flowering becomes earlier because the midsummer length of day is not so long, and the critical limit for flowering is more quickly reached. This, coupled with a longer season without frost, insures seed production.

A correct knowledge of the day-length requirements of *Perilla*, which is a particularly useful plant because of its valuable drying oils, is of considerable importance as indicating the latitudes in the United States at which it is most likely to succeed.

Salvia hispanica, or chia, as it is commonly known, is a species with very marked short-day requirements. Under the test of 13 hours of daylight each day, the plants flowered July 6. In response to one-half hour more of light each day, i. e., 13½ hours, flowering was delayed until August 17, or 42 days. With 1 hour more of light each day,

TABLE 15.—*Behavior of native and introduced species and varieties of stonecrop, Sedum (Crassulaceae), in response to length of day*

Plants	Test began	Effect of daily light exposure of[1]—																		Class
		10 hours		12 hours		12½ hours		13 hours		13½ hours		14 hours		14½ hours		18 hours		Full length of day		
		Flowered	Height	Flowered	Height	Flowered	Height	Flowered	Height	Flowered	Height	Flowered	Height	Flowered	Height	Flowered	Height	Flowered	Height	
Sedum:		*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	*Days*	*Inches*	
S. acre L. (mossy sedum)	Mar. 27	([2])		58	3	66	3	57	3	([2])		([3])		([3])		([3])		63	3	Indeterminate.
S. album L. (white sedum)	do	([2])		([2])		([2])		([2])		([2])		([3])		([3])		([3])		([2])		Long day (?).
S. dasyphyllum L. (thick-leaved sedum)	Apr. 14	([2])		([2])		([2])		([2])		([2])		76	13	([2])		([3])		84	16	Do.
S. hispanicum L. (Dreer)	Apr. 20	([2])		([2])		([2])		([2])		([2])		([2])		([2])		([2])		62	2	Do.
S. ibericum Stev. (Mount Desert nurseries)	Apr. 11	([2])		([2])		([2])		([2])		([2])		([3])		([3])		([3])		([2])		Do.(?)
S. maximum Suter	Apr. 17	([2])		([2])		81	14	([2])		86	14	103	16	([3])		([3])		134	19	Short day.
S. moranense H. B. K.	Apr. 30	29	2½	29	3½	([4])		29	3½	29	4	([2])		([3])		([3])		29	3	Indeterminate.
S. nevii Gray (native)	Apr. 20	31	2½	32	2½	31	2½	31	2½	31	4	31	5	32	5	([3])		32	4	Do.
S. sarmentosum Bunge	Apr. 30	22	3	22	3	22	3	22	3	22	4	22	3	([3])		([3])		22	3	Do.
S. sexangulare L. (tasteless sedum)	Apr. 11	50	2	50	2	50	3	50	2½	52	3	([3])		([3])		([3])		45	4	Do.
S. sieboldi Sweet	May 17	([2])		([2])		([2])		([2])		133	7	([3])		([3])		([3])		154	6	Short day (?).
S. spectabile Bor. No. 1	Mar. 27	([2])		([2])		([2])		([2])		([2])		158	12	158	12	([2])		161	13	Long day.
S. spectabile Bor. (Brilliant)	Apr. 18	([2])		([2])		([2])		([2])		111	12	143	16	([3])		([3])		132	16	Do.
S. spurium coccineum Hort. (Dreer's)	May 20	([2])		([2])		([2])		([2])		([2])		([2])		([2])		81	6	([2])		Do.
S. stoloniferum Gmel	Apr. 30	([2])		([2])		([2])		([5])		37	3	([3])		([3])		([3])		([5])		Do.
S. telephioides Michx. (native)	Apr. 14	([2])		([2])		([2])		([2])		([2])		91	14	115	17	([3])		80	16	Do.
S. telephium L. (orpine)	Mar. 27	([2])		([2])		([2])		([2])		([2])		([2])		([2])		157	10	([2])		Do.
S. ternatum Michx. (native)	Apr. 11	([6])		([6])		([6])		([6])		([6])		([6])		([6])		([3])		([6])		Indeterminate.
S. woodwardii N. E. Br	do	([2])		([2])		([2])		([2])		([2])		([2])		([2])		164	4	([2])		Long day.

[1] All lengths of day to and including 14½ hours utilized normal sunlight, dark houses being used to reduce the hours of illumination. To obtain constant illumination periods in excess of the full length of day, artificial light afforded by four 200-watt incandescent electric lights was used to supplement daylight beginning at sunset.

[2] Plants did not flower.

[3] No test was made.

[4] Plants diseased, unable to flower.

[5] Plants died.

[6] Plants flowered on Mar. 30 before the tests began.

14 hours, flowering was delayed until October 8, or 94 days. These results would indicate that chia should be grown farther south, to insure seed production before frost.

Salvia sclarea gives evidence of being a long-day plant, and if this behavior is substantiated by further tests, the plants can be expected to flower more readily much farther north.

Salvia splendens, or scarlet sage, is a plant whose flowering is delayed by the full length of the midsummer day at Washington. Its critical light period apparently lies above the longest days of that latitude.

Sedum

The data in table 15 deal with a collection of stonecrops (*Sedum*), some of which have been grown for 8 to 10 years in connection with studies of their day-length requirements. A number of these, including *S. nevii* and *S. telephioides*, found in the higher mountain sections of the Appalachians, and *S. ternatum*, which is not particular as to altitude, are native eastern species. *S. moranense*, a low-latitude species, is of Mexican origin. The rest are native to the British Isles, Europe, Asia, Japan, and north Africa. They are, in most instances, natives of very high latitudes. The species, for the most part, are correctly named; in a few doubtful cases the source of the material is given.

The stonecrops under observation fall into two rather distinct groups: (1) The herbaceous perennials, including the tall-growing, erect species *Sedum maximum*, *S. spectabile*, *S. telephioides*, and *S. telephium*, the stems of which die each autumn and are replaced by new ones arising from dormant buds formed at the ground; (2) perennials, the stems and leaves of which tend to persist throughout the winter if conditions are not too unfavorable.

It is interesting to observe that most of the common and better-known garden stonecrops have long-day requirements or are indeterminate in their flowering behavior; few have behaved as typical short-day plants in the Washington latitude. The species *Sedum acre*, *S. moranense*, *S. nevii*, *S. sarmentosum*, *S. sexangulare*, and *S. ternatum* appear to flower readily under a wide range of lengths of day ranging from 10 hours to the full length of day in the latitude of Washington. It will be observed that the time of flowering has varied little throughout the series for any one of these indeterminate species. The time of flowering in response to the inconstant full length of day is about the same as that for the constant short or long days, a relationship that should obtain for a truly indeterminate type of plant not particularly responsive to long or to short days.

Sedum spectabile is a typical long-day plant in its flowering behavior. Several strains differing more or less in growth and flower characters have been tested, and, as indicated in the tables, the very showy variety Brilliant flowers in response to a somewhat shorter length of day than No. 1, and for that reason it is somewhat earlier in its seasonal flowering. *S. spectabile* has been accredited a native of Japan, but this has been questioned, so that the original home of the species is not known. The long-day requirements of the species would indicate that it is a native of high latitudes, even though Japan may not be its home.

The native species *Sedum telephioides*, more or less abundant on rocks in the high Appalachians and eastward in the United States, is a typical long-day type of plant that has failed to flower under lengths of day much less than 14 hours long. The fact that this species flowers in June in England where the days are very long indicates that flowering is greatly favored by very long days.

In autumn this species, and also the large-growing species *Sedum telephium* and *S. spectabile,* form large winter buds at the surface of the ground and these give rise to the turios or shoots of the next spring. Tests with *S. telephioides* have shown that these resting buds are formed most readily under the shorter light exposures ranging from 10 to 13 hours daily. They were formed in abundance very early in the season on the 10-, 12-, 12½-, and 13-hour periods, but failed to appear on the 13½-hour day or any longer light period. On the 13½-hour period, flower buds likewise failed to appear. These sterile stems, however, tended to form at their tips dense clusters of large leaves resembling a sort of terminal rosette. Plants experiencing the full length of day also form the resting buds or turios under the influence of the short autumnal days unfavorable to flowering. The fixed shorter day lengths, tending to enforce dormancy at a time when temperatures are very high, have resulted in very poor plants, many of which died before the summer was over. This behavior was especially marked on the 10-hour day.

The curious stonecrop (*Sedum amplexicaule* DC.), a Mediterranean species, appears to go a step farther in autumn in modifying the tips of the shoots into small tubers bearing scalelike leaves. As the ends of the shoot become tuberized, the leaves are reduced to a mere membranous base and a subulate or attenuate blade. These tubers dry and remain viable on the ground all winter as aerial resting buds. In springtime these awaken and give rise to new plants. In this novel manner the plants are propagated and distributed readily. There is little doubt but that this seasonal behavior is related to length of day, which exerts its effect at once upon the growing bud at the end of the leafy shoot, whereas in *S. telephium* and others the bud is laid down on the crown of the plant at the ground.

Sedum telephium has proved to be one of the most distinctive stonecrops in its day-length behavior (fig. 22). There is no summer length of day in low or middle latitudes up to 39° favorable to flowering. This species flowers readily in New England and in Europe where much longer days prevail in summertime. It has never flowered at Washington, D. C., in response to the normal length of day, which approaches 15 hours only briefly during the longest days of June. Where artificial light has supplemented normal daylight from sunset to give continuous light periods of 17 hours or more this species has flowered readily.

Sedum spurium coccineum has never flowered under any length of day in the tests at Washington, D. C., where the length of day was maintained below the full length of day of midsummer.

Sedum ternatum, a native species distributed from Connecticut to Indiana and southward to Georgia, is indeterminate in its length-of-day requirements. This species flowers normally in May at Washington. In England at latitudes above 50°, however, its behavior may be somewhat different, for it is reported as flowering there in July and August, when the seasonal length of day has fallen from its greatest length of 16½ or 17 hours. This may be taken to indicate that this stonecrop flowers more quickly on a shorter length of day and is perhaps a short-day type of plant. In middle and low latitudes it would behave as an indeterminate plant in its flowering behavior, but as a short-day plant in very high latitudes having a midsummer length of day above the critical favorable for flowering.

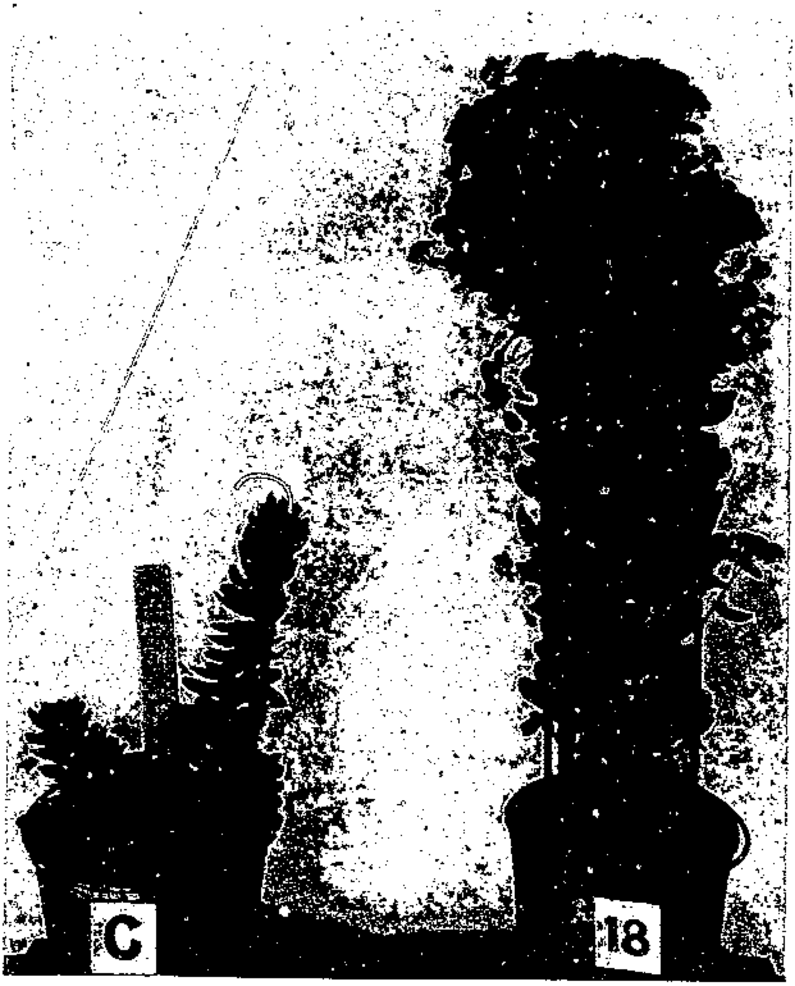

FIGURE 22.—*Sedum telephium* L. A sedum requiring very long days for flowering and never flowering in the vicinity of Washington without artificially increased lengths of day. The plant shown at right was grown in the greenhouse under artificial light from a 100-watt incandescent bulb with reflector, the light supplementing the daylight from sunset till midnight. This plant flowered March 2. The plant at left (C) experiencing the seasonal days never flowered. Tests began November 24; photographed June 16.

However, experiments conducted with this plant in the greenhouse under light during the winter of 1936–37 would indicate that temperature as well as length of day may operate to control flowering. In these tests plants were grown under cool conditions, 50° to 55° F., and warm conditions, 70° to 75° F., with natural winter illumination and with the natural daily period of illumination increased by electric light from sunset to midnight, a 200-watt tungsten filament light being used at 1 foot distance from the plants. The tests began October 28, 1936, and buds were abundantly in evidence on the illuminated plants in the cool greenhouse January 9, 1937. There was no indication of buds on the illuminated plants in the warm house at this time, and none on the control plants in either house receiving normal winter illumination. It is obvious that the longer illumination period has been effective only where cool temperatures of 50° to 55° have prevailed. This stonecrop thus behaves as does the sugar beet, the flowering of which is favored by cool temperature and long daylight. These relations between temperature and light may complicate the behavior of this species in the field, both in its normal home and when grown in other lands.

The results with the species of *Sedum* make it clear that a plant must be exposed to extremely long days or to continuous light to

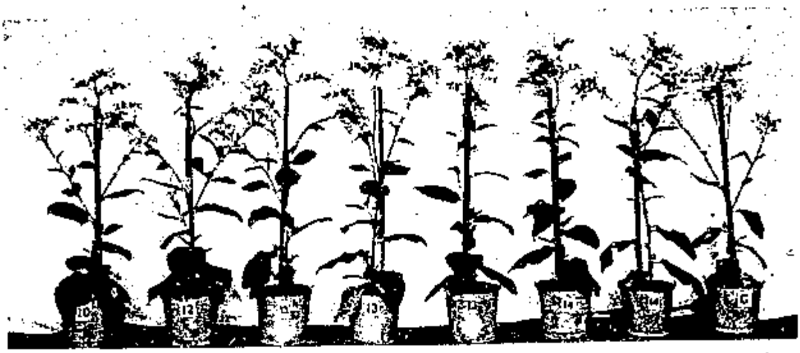

FIGURE 23.—*Nicotiana tabacum* var. T. I. No. 68. Most commercial tobaccos are indeterminate in their day-length behavior, flowering with equal readiness under nearly all day lengths. The Maryland Mammoth variety, however, requires short days to induce flowering. The early strain shown flowered as follows: 10-, 12-, 12½-, 13-, and 14-hour plants flowered June 13; 14½-hour plants, June 16, full day plants (C), June 15. Tests began May 14; photographed June 30.

determine definitely whether it is a true indeterminate plant. Its seasonal behavior in low or middle latitudes may not reveal the true story of its day-length requirements if the critical photoperiod happens to be a very long one. In the stonecrops, no length of day has been found that will completely inhibit stem formation. As a matter of fact, stem elongation without flowering is the characteristic behavior on short days, which completely inhibit flowering. Plants allowed to remain in the greenhouse through the winter for months after the normal flowering time remain vegetative and practically dormant unless the natural length of day is supplemented by artificial light. Late shoots of *S. telephioides* and others in this group failing to flower in season never flower, owing to the shortening of the day below the critical length of day favorable to flowering.

TOBACCO

The data in table 16 present the behavior of some of the more distinctive American and a few foreign types of commercial tobacco (*Nicotiana tabacum*). The dates of flowering and the heights given for each light exposure are, in most instances, based upon the behavior of five plants (fig. 23).

TABLE 16.—*Behavior of some varieties of Nicotiana tabacum L. (tobacco) in response to length of day*

Plants	Test began	Effect of daily light exposure of [1]— 10 hours: Time required for— Buds	10 hours: Flowers	10 hours: Height	12 hours: Time required for— Buds	12 hours: Flowers	12 hours: Height	13 hours: Time required for— Buds	13 hours: Flowers	13 hours: Height	14 hours: Time required for— Buds	14 hours: Flowers	14 hours: Height	16 hours: Time required for— Buds	16 hours: Flowers	16 hours: Height	18 hours: Time required for— Buds	18 hours: Flowers	18 hours: Height	Continuous light: Time required for— Buds	Continuous light: Flowers	Continuous light: Height	Full length of day: Time required for— Buds	Full length of day: Flowers	Full length of day: Height	Class
		Days	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	*Days*	*Days*	*In.*	
Xanthi variety	June 7	-----	36	44	-----	30	44	-----	35	52	-----	37	57	-----	37	46	-----	36	43	-----	35	48	-----	34	48	Indeterminate.
Connecticut Broadleaf variety, John Williams strain	do	-----	39	42	-----	36	48	-----	39	56	-----	42	58	-----	40	42	-----	40	54	-----	42	46	-----	36	48	Do.
Cash No. 117 variety	do	-----	42	56	-----	38	57	-----	45	66	-----	47	68	-----	52	56	-----	46	58	-----	51	62	-----	50	56	Do.
Maryland-Connecticut Broadleaf variety, High Leaf No. 0-8	do	-----	58	40	-----	48	39	-----	46	42	-----	61	40	-----	81	46	-----	56	39	-----	66	44	-----	58	35	Do.
Maryland-Connecticut Broadleaf variety, No. 114	do	-----	49	44	-----	60	43	-----	35	54	-----	84	57	-----	73	46	-----	81	52	-----	80	45	-----	59	46	Do.
Judy's Pride variety, White Burley	do	-----	57	26	-----	66	27	-----	75	28	-----	80	34	-----	66	35	-----	84	40	-----	84	36	-----	75	22	Do.
Cuban variety, high nicotine strain No. 111	do	-----	50	50	-----	71	48	-----	42	53	-----	51	55	-----	49	52	-----	42	50	-----	40	52	-----	49	52	Do.
Sumatra variety	do	-----	50	62	-----	41	58	-----	51	68	-----	56	64	-----	47	49	-----	50	50	-----	65	52	-----	49	60	Do.
Maryland Mammoth variety	do	-----	61	51	-----	73	64	-----	73	61	-----	88	66	-----	130	59	-----	132	60	-----	([2])	----	-----	90	59	Short day.
Extra early tobacco	May 14	18	30	40	19	30	45	18	30	45	18	30	44	-----	([2])	----	-----	([2])	----	-----	([2])	----	18	32	42	Indeterminate.
Ambalema variety	do	113	129	79	113	132	80	115	132	88	125	139	57	-----	([2])	----	-----	([2])	----	-----	([2])	----	123	137	68	Do.

[1] Light exposures of 16 hours, 18 hours, and continuous light were obtained by the addition of artificial light furnished by four 200-watt incandescent bulbs with reflectors from sunset throughout the season.

[2] No test made.

With the single exception of the Maryland Mammoth tobacco, all the forms whose responses are known appear to be little affected by wide differences in length of day. In this respect they show an indeterminate behavior. A comparison of the mean date of first flowering for the periods below the full length of day with periods of daily illumination in excess of the full length of day and with continuous illumination indicates that the time of flowering of Xanthi, the John Williams strain of Connecticut Broadleaf, and Cash are little if at all affected even by continuous illumination. They are typical examples of the class of plants that have been called indeterminate for the reason that they flower with equal readiness and freedom under all lengths of day from 10 hours to continuous illumination.

The two strains of Maryland-Connecticut Broadleaf designated as High Leaf No. 0–8 and No. 114 show a somewhat different behavior. Both exhibit a slight tendency toward delayed flowering in response to periods of illumination in excess of the longest days at Washington, and to continuous illumination. It has long been known that these strains in the field have been characterized by the production of late-flowering plants of high-leaf number. Delayed flowering has been more or less consistently correlated with high-leaf number. It is obvious that this behavior is not that of the truly indeterminate variety Xanthi, which shows no delay in flowering in response to long light periods. From the fact that hastened flowering is a response to shortened days, these strains show short-day tendencies. The culmination of the short-day tendency in tobacco has found strong expression in the Maryland Mammoth variety, but even in this variety and the two Maryland-Connecticut Broadleaf strains under discussion, factors of the environment other than length of day may hasten or delay the time of flowering. With the exception of the Maryland Mammoth type, which is hastened into flowering by short days, practically all the American commercial varieties of tobacco show an indeterminate behavior.

It will be noted that there are fixed striking varietal differences in earliness of flowering, as between Xanthi and Ambalema, and extreme changes in length of day have not altered these relations. These striking strain or varietal differences have nothing to do with chromosome number, since the somatic chromosome number of *Nicotiana tabacum* is 48, and none of the varieties shows any departure from this.

Discovery of the length-of-day relationships of plants, as established by Garner and Allard,[3] was based largely upon the delayed flowering behavior of the Maryland Mammoth variety of tobacco, now known to be dependent upon length of day.

ANNUAL FLOWERING PLANTS

The plants whose behavior is presented in table 17 represent a wide range of families and include some of the most familiar annual garden flowers. Two of these, *Steironema ciliatum* and the willow (*Salix humilis*), are native wild plants of the Washington vicinity, the former showing the behavior of a typical long-day plant with a well-defined lower limit in its flowering scale, below which flowering has never been observed to take place in tests carried on for many years.

[3] GARNER, W. W., and ALLARD, H. A. EFFECT OF THE RELATIVE LENGTH OF DAY AND NIGHT AND OTHER FACTORS OF THE ENVIRONMENT ON GROWTH AND REPRODUCTION IN PLANTS. Jour. Agr. Res. 18: 553–606, illus. 1920.

This plant flowers in response to 12½ hours of light, but produces only sterile vegetative growth with some stem elongation in a 12-hour day. Upright stem elongation is almost entirely inhibited in response to 10 hours of light, but more or less shortened or prostrate stems arise that produce abundant leafage. Somewhere between 12 and 12½ hours there appears to be a critical period which favors flower-bud formation as the daily light duration is increased. This critical limit for flowering seems to be rather sharp, as there has been no delay in flowering with 12½ hours of daylight. The majority of the cultivated garden plants show an indeterminate behavior, and for this reason they are adapted to garden culture throughout a wide range of latitudes extending from the extreme South to the far North. This behavior is readily seen on inspection of the results in table 17.

TABLE 17.—*Behavior of some plants of 13 families in response to length of day*

Plants	Family	Test began	Effect of daily light exposure of— 10 hours: Days required for— Buds	10 hours: Flowers	10 hours: Height, inches	12 hours: Days required for— Buds	12 hours: Flowers	12 hours: Height, inches	12½ hours: Days required for— Buds	12½ hours: Flowers	12½ hours: Height, inches	13 hours: Days required for— Buds	13 hours: Flowers	13 hours: Height, inches	13½ hours: Days required for— Buds	13½ hours: Flowers	13½ hours: Height, inches	14 hours: Days required for— Buds	14 hours: Flowers	14 hours: Height, inches	14½ hours: Days required for— Buds	14½ hours: Flowers	14½ hours: Height, inches	Full length of day: Days required for— Buds	Full length of day: Flowers	Full length of day: Height, inches	Class
Aquilegia canadensis L. (wild columbine).	Ranunculaceae	Mar. 27	4	25	19	4	28	19	----	(1)	----	4	36	30	----	(1)	----	14	36	30	----	(1)	--	4	36	30	Short day.
Anagallis linifolia L.	Primulaceae	May 14	25	30	9	25	31	9	23	27	9	28	37	11	25	27	7	27	31	11	31	34	11	27	29	10	Indeterminate.
Caryopteris incana (Thunb.) Mig.	Verbenaceae	June 5	26	38	13	26	38	16	----	(1)	----	24	35	16	----	(1)	----	54	71	28½	----	(1)	--	59	71	28	Short day.
Centranthus macrosiphon Boiss.	Valerianaceae	May 14	29	48	5	34	38	3½	34	38	3½	32	46	8	20	34	8	29	38	7	27	35	7	21	35	8	Indeterminate.
Cleome spinosa Jacq. (spider-flower).	Capparidaceae	May 31	26	38	28	27	35	28	----	(1)	----	27	36	34	----	(1)	----	28	40	36	----	(1)	--	28	38	65	Do.
Clerodendron thomsonae Balfour.	Verbenaceae	May 24	24	52	19	24	52	19	28	52	18	29	52	21	28	52	----	32	52	22	28	38	22	28	57	18	Do.
Cobaea scandens Cav.	Polemoniaceae	May 26	24	53	46	36	91	41	----	(1)	----	55	91	46	----	(1)	----	60	92	60	----	(1)	--	64	97	60	Short day.
Impatiens balsamina L. (garden balsam).	Balsaminaceae	June 23	20	28	14	20	28	18	----	(1)	----	20	29	19	20	28	17	----	(1)	----	----	(1)	--	30	38	21	Indeterminate.
Oenothera:																											
O. missouriensis Sims (native West and Southwest).	Onagraceae	May 21	----	(2)	--	----	(2)	----	----	(2)	----	----	(2)	--	----	(1)	----	22	35	7	22	38	9	21	36	7	Long day.
O. speciosa Nutt. (native West and Southwest).	do	Apr. 16	15	37	--	13	35	---	13	36	5½	15	50	10	15	10	9	15	37	9	15	40	9	15	41	9	Indeterminate.
Portulaca grandiflora Hook.	Portulacaceae	May 11	----	11	4	----	11	1½	----	(1)	----	----	10	3	----	10	3½	----	10	4	----	10	4	----	10	4	Do.
Salix humilis Marsh. (willow).	Salicaceae	Apr. 10	68	(3)	--	55	(3)	----	60	68	22	61	(3)	--	61	(3)	----	61	76	----	----	(4)	--	----	(4)	--	Short day.
Statice armeria var. *laucheana* (Bailey) (F. T. Hubbard).	Plumbaginaceae	Apr. 22	30	41	5	24	29	6	30	37	5	26	27	6	26	40	6	25	29	6	37	47	6	25	33	5	Indeterminate.
Steironema ciliatum (L.) Raf.	Primulaceae	Apr. 15	----	(2)	--	----	(5)	----	56	65	21	87	93	24	49	61	19	48	65	25	49	68	23	49	68	20	Long day.
Trachymene caerulea R. Graham.	Umbelliferae	May 14	17	38	13	27	45	20	28	40	16	29	49	22	25	45	18	29	49	25	30	53	22	17	41	13	Indeterminate.
Verbena hybrida Hort.	Verbenaceae	May 29	19	34	6	13	26	7	----	(1)	----	28	41	8	----	(1)	----	27	44	8	----	(1)	--	20	40	8	Do.
Vinca minor L.	Apocynaceae	June 7	18	26	16	18	23	12	----	(1)	----	----	(1)	--	----	(1)	----	----	(1)	----	----	(1)	--	18	23	12	Do.

[1] No test made.
[2] Leafage only.
[3] Buds fell.
[4] Never budded.
[5] Leafage and stems.

Some Miscellaneous Annual and Woody Plants

The plants presented in table 18, most of which are garden ornamentals, include typical examples of all the classes of plants known as long-day, short-day, and indeterminate types. A few of these are woody plants, but the majority are herbaceous annuals.

The indeterminate types are adapted to the short summers of far northern as well as to southern latitudes. Wherever grown, their ready response to long or to short days enables them to behave as early flowering plants. One of the best examples of a woody plant of indeterminate flowering behavior is turkscap (*Malvaviscus conzatti*). This plant is a tender shrub suitable for out-of-doors culture only in the warm regions of the South, but its readiness to flower in response to long as well as to short days would adapt it to the gardens of northern latitudes if the temperature requirements were similar to those of the hardy althaea (*Hibiscus syriacus*). Easily killed by frost, it must remain in regions where warm winters prevail, although its length-of-day behavior makes it well adapted to the summers of the North.

Bougainvillea and poinsettia are typical short-day plants, but, like the turkscap, are highly sensitive to frost, and for that reason their out-of-door culture must be limited to subtropical regions. Even if their wood were hardy, their short-day requirements would bring their flowering into the cold days of autumn and early winter, a behavior very rarely shown even by the hardiest northern shrubs, witch-hazel (*Hamamelis virginiana* L.) alone being characterized by this unusual behavior.

Convolvulus sepium, a most pernicious native weed, is a typical long-day plant, which remains strictly vegetative under lengths of day up to 13½ hours long. Plants given the full length of day flowered more quickly than the 13½-hour plants, showing that the latter had not yet experienced the most favorable long day conducive to early flowering. Under short-day conditions, this plant transfers its vegetative activity from aerial stem growth to production of fleshy underground stems in large measure, whereby it quickly invades new areas and becomes deeply established in suitable soils. The requirement of long days for flowering and readiness to produce persistent underground stems as the days shorten adapt this plant to northern rather than to far-southern latitudes. As a perennial plant, it has the most favorable temperature and day-length relations to qualify it as a troublesome weed, a reputation which it has gained accordingly.

The several species of *Ipomoea* tested, among which several varieties of sweetpotatoes were included, have shown varied day-length requirements.

Three distinct varieties of sweetpotatoes were grown, Yellow Jersey, Porto Rico, and the Southern Queen. All these were grown in similar containers and soils. The largest container used was a box holding about 2 cubic feet of sandy loam, which had been well supplied with a suitable chemical fertilizer. The smaller containers consisted of 14-quart galvanized-iron buckets, one series of which was filled with the same soil used in the larger container with no fertilizer added. Another series was grown in a friable, black, unfertilized muck. In these tests sprouts were taken from the same potato throughout, in order to eliminate possible individual variations.

TABLE 18.—*Behavior of some species of plants of 6 families in response to length of day*

Plants	Family	Test began	Effect of daily light exposure of— 10 hours			12 hours			12½ hours			13 hours			13½ hours			14 hours			14½ hours			Full length of day			Class
			Days required for— Buds	Days required for— Flowers	Height, inches	Days required for— Buds	Days required for— Flowers	Height, inches	Days required for— Buds	Days required for— Flowers	Height, inches	Days required for— Buds	Days required for— Flowers	Height, inches	Days required for— Buds	Days required for— Flowers	Height, inches	Days required for— Buds	Days required for— Flowers	Height, inches	Days required for— Buds	Days required for— Flowers	Height, inches	Days required for— Buds	Days required for— Flowers	Height, inches	
Abutilon hybridum Hort.	Malvaceae	May 29	29	50	9	35	54	12	----	[1]	----	32	40	----	----	[1]	----	----	[1]	----	----	[1]	--	47	54	18	Indeterminate.
Althaea rosea (L.) Cav. (hollyhocks).	do	May 10	----	[1]	---	----	[2]	---	----	58	31	----	58	38	----	54	31	----	[1]	----	----	[1]	--	----	54	39	Long day.
Bryophyllum pinnatum (Lam.) Kurz.	Crassulaceae	May 18	9	99	50	----	[2]	---	----	[2]	----	----	[2]	----	----	[2]	----	----	[2]	----	----	[2]	--	----	[2]	--	Short day.
Buginvillea glabra Choisy (bougainvillea).	Nyctaginaceae	May 24	28	45	38	36	57	40	69	88	56	96	157	60	145	164	75	103	153	50	143	157	53	131	157	--	Do.
Cheiranthus allionii Hort. (Dreer's).	Cruciferae	Apr. 25	----	[3]	---	----	[3]	---	----	[1]	----	----	[4]	----	----	[4]	----	----	[4]	----	----	[3]	--	----	75	6	Long day.
Convolvulus:																											
C. sepium L.	Convolvulaceae.	May 19	----	[2]	---	----	[2]	---	----	[1]	----	----	[2]	----	44	59	40	----	[1]	----	----	[1]	--	35	49	45	Do.
C. tricolor L.	do	May 22	----	[5]	---	110	116	20	----	[1]	----	110	116	11	----	[1]	----	67	71	14	----	[1]	--	62	67	14	Do.
Euphorbia:																											
E. heterophylla L. (annual poinsettia).	Euphorbiaceae	May 13	33	40	12	35	40	10	----	[1]	----	46	53	11	----	[1]	----	----	[4]	----	----	[1]	--	----	[4]	--	Short day.
E. marginata Pursh. (snow-on-the-mountain).	do	do	27	32	5	33	42	7	----	[1]	----	27	32	6	----	[1]	----	----	[1]	----	----	[1]	--	27	30	6	Indeterminate.
E. pulcherrima Willd. (poinsettia).	do	May 16	32	65	47	39	44	53	48	180	66	107	179	76	162	191	74	163	193	76	163	195	91	158	197	70	Short day.
Hibiscus syriacus (L.) (althea)	Malvaceae	Mar. 27	----	[2]	---	----	[2]	---	95	117	30½	96	123	47½	95	126	45½	103	136	44	106	144	52	103	130	44	Long day.
Iberis umbellata L., candytuft (Dreer's Rose Cardinal).	Cruciferae	May 14	13	37	12	13	30	11	17	37	11	13	30	7	17	41	13	17	30	13	13	30	9	17	30	12	Indeterminate.
Ipomoea:																											
I. batatas L. (sweetpotato) var. Southern Queen.	Convolvulaceae.	May 18	33	50	38	33	57	36	----	[2]	----	----	[2]	----	----	[2]	----	----	[2]	----	----	[2]	--	----	[2]	--	Short day.
I. hederacea Jacq. (Dreer's Imperial).	do	May 16	13	29	24	21	38	36	----	[1]	----	13	38	60	26	56	56	----	[1]	----	----	[1]	--	62	75	50	Do.
I. purpurea (L.) Roth. (Dreer's Double Rose Marie).	do	May 10	13	27	26	19	32	33	19	32	29	19	33	42	21	34	40	25	69	46	25	72	50	25	72	--	Do.

I. quamoclit L. (cypress-vine).	do	do	22	34	33	19	35	44	21	36	54	21	35	30	22	35	45	21	36	38	25	43	47	25	46	45	Indeterminate.
I. setosa Ker	do	May 25	7	21	58	9	27	45	9	32	48	11	37	50	9	37	50	9	41	60	9	42	60	9	26	60	Short day.
I. tricolor Cav. (Dreer's Heavenly Blue).	do	May 21	14	32	50	14	32	50	----	(1)	----	14	33	56	----	(1)	----	18	39	50	----	(1)	..	20	38	56	Indeterminate.
Kalanchoe:																											
K. laxiflora Baker	Crassulaceae	May 8	----	(1)	---	----	(1)	---	173	239	38	173	199	47	----	(1)	----	173	192	51	173	204	50	173	192	51	Do.
K. tubiflora (Harv.) Hamet.	do	June 10	----	(2)	---	----	(2)	---	113	140	32	143	171	35	147	183	29	----	(1)	----	----	(1)	..	147	(6)	..	Do.
Labularia maritima (L.) Desv. (Dreer's Little Gem or Carpet of Snow).	Cruciferae	May 9	----	(7)	---	----	(7)	----	----	(7)	----	----	(7)	----	----	(7)	----	----	(7)	----	----	(7)	..	----	(7)	..	Do.
Malvaviscus conzatti Greenm. (turkscap).	Malvaceae	do	29	54	31	32	63	37	32	63	42	32	63	44	32	63	42	37	63	47	37	66	44	50	63	55	Do.
Matthiola incana (L.) R. Br.	Cruciferae	July 12	----	(5)	---	----	(6)	----	----	(1)	----	----	(9)	----	----	(10)	----	----	(1)	----	----	(1)	..	33	41	8	Long day (?).
Mirabilis jalapa L.	Nyctaginaceae	May 9	26	36	9	26	37	13	26	37	19	26	41	15	26	41	21	26	41	19	30	47	27	26	44	12	Indeterminate.
Tropaeolum majus L.	Cruciferae	May 7	31	40	10	31	39	10	----	(1)	----	31	30	12	35	43	14	44	49	12	32	36	15	35	43	11	Do.

1 No test made.
2 Plants never budded.
3 Leafage only developed.
4 Plants died.
5 Prostrate stems only developed.
6 Plants never flowered.
7 Plants flowered all summer.
8 Rosettes formed.
9 Stem elongation only.
10 Much stem elongation.

The Southern Queen was the only variety in these tests that appeared to show any response to length of day, and profuse flowering occurred only on the 10-hour and 12-hour exposures in all soils and in all containers. Flowering was somewhat delayed and less profuse in the smaller containers, however.

It would appear from these tests that flowering is more easily induced in the Southern Queen than in the Porto Rico or the Jersey varieties by length of day. These tests would indicate that flowering in the sweetpotato is favored by short days, rather than that a long period of vegetative growth is required to prepare the plants for flowering, as has often been held to explain the stubborn and irregular flowering of sweetpotatoes wherever grown in the field. The plants in the tests described were bedded March 18, pulled and placed in the containers April 28 when 7 inches high, and from the time of bedding budded in 94 days and flowered in 111 days on the 10-hour day. In no instance did any of the blossoms produce seed, although flowering continued throughout the entire summer.

Amaranthaceae, Asclepiadaceae, Caryophyllaceae, Cucurbitaceae, Iridaceae, Liliaceae, and Scrophulariaceae

With two exceptions the plants listed in table 19 show an indeterminate behavior in their flowering with respect to length of day (fig. 24).

In its flowering behavior the native blue-eyed grass (*Sisyrinchium gramineum*) is indeterminate. This plant, however, showed an interesting response to the short length of day of 10 hours. The flattened flower stems at the apex soon after flowering took place produced one or more leafy propagules that readily rooted. These are shown in figure 25. This habit is identical with that of the tropical house plant *Marica northiana* Ker., which flowers in early spring in the greenhouse and produces new readily rooting plant units at the summit of the flower stems. No other day length has stimulated the growth of these plantlets in the case of the blue-eyed-grass. This is not encountered outdoors, since no length of day as short as 10 hours prevails during the growing season (fig. 26).

Classification of Some Plants Based on Early Studies

Only brief mention need be made of the behavior of the plants presented in table 20. In the yams (*Dioscorea*), arrowhead (*Sagittaria*), the potatoes, var. McCormick and *Solanum demissum*, and the groundnut (*Glycine apios*), tuber formation is initiated or greatly favored by shortened days of 13 hours or less. In the Medellin bean (*Phaseolus coccineus*), the roots were remarkably thickened or tuberized under a 10-hour day, and flowering was also favored by short days.

Hibiscus moscheutos and *H. sabdariffa* are two species showing diametrically opposite behaviors, the former flowering only on lengthened days and the latter, as a typical short-day plant, flowering only on very low light-darkness ratios.

FIGURE 24.—*Celosia argentea* L., lilliput (Dreer). A plant but little affected by extreme changes in length of day. The plants flowered as follows: 10, 12, 13, and 14 hour, June 18, full day (C), July 3. Tests began May 22; photographed June 30.

FIGURE 25.—*Sisyrinchium gramineum* Curtis, blue-eyed-grass showing propagules favored only on the 10-hour day at the ends of the flower stems. Controls at right (C). The formation of similar propagules is the usual behavior of the tropical house plant *Marica northiana* Ker. These propagules do not appear on the plants experiencing the full length of day in the latitude of Washington, because a sufficiently shortened day length does not intervene before killing frost. Tests began March 30; photographed September 17.

FIGURE 26.—*Gomphrena globosa* L. Globe-amaranth. A plant but little affected by length of day. The plants flowered as follows: 10- and 12-hour day, June 15; 12½-hour day, June 18; 13- and 13½-hour day, June 15; 14-hour day, June 23; 14½-hour day, June 17; full day (C), June 14. Tests began May 13; photographed August 22.

TABLE 19.—*Behavior of some species of plants of seven families in response to length of day*

Plants	Family	Test began	Effect of daily light exposure of—: 10 hours: Days required for— Buds	10 hours: Flowers	10 hours: Height, inches	12 hours: Days required for— Buds	12 hours: Flowers	12 hours: Height, inches	12½ hours: Days required for— Buds	12½ hours: Flowers	12½ hours: Height, inches	13 hours: Days required for— Buds	13 hours: Flowers	13 hours: Height, inches	13½ hours: Days required for— Buds	13½ hours: Flowers	13½ hours: Height, inches	14 hours: Days required for— Buds	14 hours: Flowers	14 hours: Height, inches	14½ hours: Days required for— Buds	14½ hours: Flowers	14½ hours: Height, inches	Full length of day: Days required for— Buds	Full length of day: Flowers	Full length of day: Height, inches	Class
Amaranthus sp. (Dreer Sunrise)	Amaranthaceae	June 5[1]			17			10		(2)				26		(2)				19		(2)				36	Indeterminate.
Anthirrhinum:																											
A. majus L. (Dreer Dwarf Golden Queen)	Scrophulariaceae	May 31	28	45	16	24	35	12		(2)		20	33	14		(2)		20	35	16		(2)		20	33	13	Do.
A. majus L. (Dreer Giant Crimson King)	do	do	28	31	16	19	32	15		(2)		20	35	20		(2)		20	35	20		(2)		18	35	18	Do.
Asparagus officinalis L. (asparagus)	Liliaceae	May 9	105	113	31	105	114	26	105	112	31	110	120	27	106	118	32	104	110	32	114	121	40	106	110	31	Do.
Celosia:																											
C. argentea L. (Dreer lilliput)	Amaranthaceae	May 22		27	12½		27	12		(2)			27	12		(2)			27	12		(2)			42	17	Do.
C. cristata L. (Dreer)	do	May 14[3]			7			4			4			8			8			15			22			19	Do.
Dianthus:																											
D. barbatus L. (Dreer Midget single)	Caryophyllaceae	May 26		(4)			(4)			(2)			(5)			(2)			(5)			(2)			(5)		(?)
D. chinensis L. (Dreer)	do	May 16	32	46	11	13	28	10	11	19	5½	29	39	14	28	39	14	12	28	7	15	35	9	11	25	6	Indeterminate.
D. plumarius L. (Dreer)	do	June 5	52	63	18	57	66	16	64	74	18		(6)			(6)		43	64	15	38	47	14	41	56	16	Do.
Godetia grandiflora Lindl.	Amaranthaceae	May 16	32	(7)		19	(7)			(2)		19	39	15		(2)		19	40	12		(2)		16	61	7	Long day.
Gomphrena globosa L.	do	May 13	21	33	8	21	33	10	21	36	11	23	32	8	21	33	9	21	41	15	21	35	12	18	32	10½	Indeterminate.
Lagenaria leucantha (Duch.) Rusby (African pipe gourd).	Cucurbitaceae	May 27	4	18	27	4	18	21		(2)		4	22	21		(2)			(2)			(2)		4	22	18	Do.
Mormodica:																											
M. balsamina L. (balsam-apple)	do	May 16	13	36	18	13	27	20		(2)			(2)			(2)			(2)			(2)		40	34	35	Do.
M. charantia L. (balsam-pear)	do	do	13	27	38	13	26	28		(2)			(2)			(2)			(2)			(2)		15	27	18	Do.
Morton No. 2516 (Oaxaca, Mexico)	Asclepiadaceae	June 4	34	52	60	23	44	50		(2)		41	62	60		(2)		49	77	60		(2)		36	71	60	Short day.
Morton No. 2560 (Oaxaca, Mexico)	do	do		(5)		42	69	60		(2)		25	50	56		(2)		25	51	66		(2)		36	70	60	Indeterminate.
Sisyrinchium gramineum Curtis (blue-eyed-grass; native)	Iridaceae	Mar. 30		43	8		44	5		(2)			49	13		(2)			51	8		(2)			63	10	Do.
Yucca filamentosa L.	Liliaceae	Apr. 28		(4)			(4)			(4)			(4)	1		(4)			(4)			(4)			(4)		Do.

[1] Plants in bud when the tests were begun; all produced very showy crimson leafage.
[2] No test made.
[3] Plants in bud when tests began; all flowered throughout all the tests; all very showy.
[4] Leafage only.
[5] Stem elongation; no flowers.
[6] Stem growth only.
[7] Never flowered.
[8] Never budded.

TABLE 20.—*Behavior of some plants representing various families of the classes Monocotyledonae and Dicotyledonae to length of day* [1]

CLASS MONOCOTYLEDONAE

Species	Family	Flowering behavior as the days are shortened below continuous illumination	Class
Dioscorea:			
D. divaricata Blanco (cinnamon-vine).	Dioscoreaceae	Aerial tubers formed by short days of 13 hours or less; most abundantly formed on 10- and 11-hour day.	Short day (?).
D. alata L. (edible yam, P. I. 46801 and 47001).	do	Enormous increase in tuber size on shortened days.	Do.
Gladiolus gandavensis Van Houtte.	Iridaceae	Flowering inhibited below a 12-hour day.	Long day.
Iris florentina L. (early iris)	do	Hastened into early flowering in winter by addition of weak light from sunset.	Do.
Sagittaria latifolia Willd. (arrowhead).	Alismaceae	Flowering initiated and tuber formation hastened by shortened days.	Short day.
Zea mays L. (Peruvian corn variety).	Gramineae	Flowering hastened by shortened days	Do.

CLASS DICOTYLEDONAE

Species	Family	Flowering behavior as the days are shortened below continuous illumination	Class
Amaranthus hybridus L. (pigweed).	Amaranthaceae	Flowering little affected by length of day.	Indeterminate.
Calonyction aculeatum (L.) House (moonvine).	Convolvulaceae	Flowered with equal readiness under long and short days.	Do.
Clematis paniculata Thunb. (clematis).	Ranunculaceae	Flowered with day lengths above 10 hours.	Long day.
Dolichos biflorus L. (kulthi bean).	Leguminosae	Hastened and profuse flowering below 13 hours.	Short day.
Dracocephalum virginicum (L.) Britton (false-dragonhead).	Labiatae	No flowering on short days of 10 hours	Long day.
Glycine apios L. (groundnut; native).	Leguminosae	Flowered on long days; tuber formation favored by shorter days.	Do.
Hibiscus:			
H. moscheutos L. (wild mallow; native).	do	Short days inhibit flowering	Do.
H. sabdariffa L. (roselle)	do	Flowering greatly hastened by short days; plants did not flower in response to full day until November.	Short day.
Impatiens biflora Walt. (native jewelweed).	Balsaminaceae	Flowering hastened by shortened days.	Do.
Maurandya lophospermum Bailey (lopseed).	Scrophulariaceae	Flowered with equal readiness under all lengths of day from 10 hours to full day.	Indeterminate.
Phaseolus coccineus L. (Medellin bean from South America, F. P. I. No. 46145)	Leguminosae	Flowered best on short days, with a remarkable enlargement of the roots into tubers in 10 hours.	Short day.
Polygonum pennsylvanicum L. (smartweed; native).	Polygonaceae	Flowered under short and long days, but flowering hastened with increase in length of day.	Long day.
Rhaphanus sativus L. (radish)	Brassicaceae	Flowering hastened by long days; hypocotyl enlargement by short days.	Do.
Rumex:			
R. abyssinicus Jacq	Polygonaceae	Flowering initiated by a day length below 12 hours.	Short day.
R. acetosella L. (sorrel)	do	Flowered on long days; underground stems enormously developed under short days.	Long day.
Solanum:			
S. demissum Lindl	Solanaceae	Flowering favored by long days; tuber formation by short days.	Do.
S. tuberosum L. (McCormick variety).	do	Short days favored tuber formation	Long day (?).
Spinacea oleracea L. (spinach, Savoy variety).	Chenopodiaceae	Flowering initiated and hastened by long days.	Do.
Viola:			
V. fimbriatula J. E. Smith	Violaceae	Flowered under all lengths of day, but short days of 10 to 12 hours stimulate the formation of blue, petaliferous flowers of spring; long days replaced these with cleistogamic flowers.	Short day.
V. papilionacea Pursh	do	Behavior similar to *V. fimbriatula*	Do.

[1] These plants were studied shortly after the discovery of length of day as a factor in plant behavior, when facilities were not available for a graduated series of tests involving small changes in the daily light period.

The violets (*Viola fimbriatula* and *V. papilionacea*) are, in a sense, indeterminate in their flowering habits, but the completeness of the flower itself depends upon the length of day experienced, a behavior comparable to that of the hogpeanut. On long days favorable to increased vigor accompanied by an excessive growth of leafage with large blades and long petioles, the flower finds conditions less favorable for complete development, and greenish flowers and cleistogamy are attendant features of floral expression. On short days, leafage is sparse, the leaves are small and short-petioled, and the development of short, prostrate stems is favored. Under these conditions of reduced vegetative expression, the blue petaliferous flower makes its appearance. It is obvious that the complete flower characterized by fully developed blue color and floral parts is related to short days. These contrasted differentiations of flower structure simply represent tendencies toward and away from extreme vegetative expression. The greatest reduction in the form and showiness of the blossoms prevails when the vegetative forces have reached their maximum dominance. In view of these facts they are classified as of short-day habit.

APPLICATION OF RESULTS OF KNOWLEDGE OF THE LENGTH-OF-DAY REQUIREMENTS OF PLANTS

Man has long had plant life under observation and for ages has successfully cultivated plants for his needs. Wherever he has gone he has carried his plants with him and has made a success or failure of his introductions into the new lands. As we find the older plants in culture today, they are successful in their natural regions, but long ages of experimentation are back of the culture of every plant. Today the great crops with their myriads of varieties and strains are adapted to many conditions of soil, season, and climate. Many specialized conditions have had to be met, for every plant has its soil requirements, its humidity and temperature requirements, its light requirements, and its demands for a certain length of season between frosts. Length of day is now known to be an important requirement also, but this was not definitely recognized until within comparatively recent years.

Wild plants in their wanderings have always been forced to adjust themselves to length of day, and every successful wild plant represents an adjustment to this factor as much as to any other factor of the environment. It is a factor that comes into operation along lines of latitude and not in eastward or westward trends.

The manner in which this factor operates can be illustrated by the poinsettia. Its day-length requirements are rather rigidly fixed, with a critical point near 12 to 12½ hours required for flowering and for the bract coloration which gives it value as an ornamental. It is a native of the American Tropics and thrives out of doors in tropical and subtropical regions. Even in the vicinity of Washington, D. C., it flowers and colors only during the shortest days of the wintertime, for a seasonal swing toward longer days in June of only one-half hour is sufficient to carry the poinsettia into the length of day unfavorable for flowering. The writers are informed that this behavior actually prevails almost on the Equator in Brazil and northward, so that even within these warmer ranges the poinsettia has a seasonal flowering associated with the winter months. Naturally, this frost-sensitive plant can be grown for its showy bracts northward only during the cold autumnal season. This compels the gardener to treat it as a greenhouse plant, for the reason that a 12-hour day, which initiates flowering and coloration, is experienced simultaneously over all the earth around September 21, and this date is close to the occurrence of frost in most northern latitudes. This situation, of course, can be changed by artificial regulation of the seasonal length of day.

The Klondyke cosmos (*Cosmos sulphureus* Cav.), a beautiful vividly orange species, is a native of Mexico, and the present cultivated stocks are traced to introductions in 1896. The first cultivated strains of this species have rather low length-of-day requirements around 13 to 13½ hours, and for that reason they could not flower at all in northern latitudes before frost, even in the vicinity of Washington. They were adapted only to garden culture southward, and they found a place in the gardens of eastern South Carolina and farther south, where the shorter midsummer days initiated earlier flowering and the season of autumnal frost was postponed. The senior writer, some years ago, while on a visit in central Massachusetts, saw much of this cosmos growing in the local gardens. In late September it had attained a huge stature, but showed no indications of flowering. This strikingly illustrates what an unsuitable day length does to the plant when it is carried far away from its native home of relatively short Mexican days, and demonstrates the futility of the culture of such late strains in the northern latitude.

Within recent years the gardener by selection has found and isolated earlier strains of the Klondyke cosmos, which are offered to the trade under the names Early Orange Flare, Early Golden, and the like. These strains are early flowering because they have a higher critical day length for flowering, which enables them to flower early in the summer at Washington, D. C., and to be grown much farther north. This is a nice illustration of a plant valuable in garden culture far north of Mexico that has been developed within comparatively recent years, the usefulness of the plant depending upon the fact that selection, though perhaps not consciously determined by a knowledge of the action of day length, has been actually concerned with response to this factor.

In the tests at Washington, many stonecrops have refused to flower under the natural length of day, most striking among these being a species of high Old World latitudes (*Sedum telephium*), which requires a long photoperiod. This plant has often been grown south of New England, but has not flowered because its critical length of day for flowering is higher than the longest days of lower latitudes. It flowers in northern New England where a length of day long enough to initiate flowering is encountered.

Modern agriculture has seen the introduction of a very large number of plants into the United States, some of which are crop plants of the highest value. These have been tested far and wide, oftentimes with failures that now are traceable in many instances to maladjustments to favorable lengths of day during the growing season. A better knowledge of the day-length requirement of some of these plants would have shown that certain of them could succeed only in the North, whereas others required lower latitudes. The various perillas, whose seed contains a valuable drying oil, are of interest in this connection. A number of Old World strains of *P. frutescens* and the variety *nan-*

kinensis have been grown at the suggestion of the Division of Drug and Related Plants, with a view to determining their day-length requirements. The species as a whole is an assemblage that flowers best on shortened days, and the critical length of day is such that in the latitude of Washington the strains in question barely flower in time to escape frost. They become plants of large stature with slow and delayed flowering. It is obvious that these plants are near the upper limit of their day-length requirements and should be grown farther south, although only just far enough south to obtain the largest plants and highest yields of seeds before frost. How reduction of day length affects flowering and stature was shown in table 14.

Chia (*Salvia hispanica*) and *Guizotia abyssinica*, likewise valuable oil-bearing plants, which were also grown under the direction of the Division of Drug and Related Plants, have shown themselves to be plants of pronounced short-day behavior and, like *Perilla*, should be grown south of this latitude rather than north. In contrast *Lallamantia iberica* would perhaps give larger plants and yields of seed if grown north of this latitude.

It appears that long-day plants having a critical photoperiod of 14 to 15 hours or longer should be tried in northern regions, for they could not well be adapted to southern culture. The more sharply a plant flowers around a certain length of day, the more important becomes the question whether this day length corresponds to high or to low light-darkness ratios. Such plants have rather rigid day-length requirements and are adapted to particular latitudes only. Indeterminate plants that flower about equally well in response to all lengths of day are the most amenable to culture, since as a rule they can be grown from the Tropics to the poles so far as concerns day-length requirements. Very useful plants belonging in this category include the tomato, pepper, tobacco, and many others.

The long-day and short-day plants offer greater opportunities for intelligent selection, as their day-length requirements are often rather narrow. Many plants of both groups may show a critical limit for flowering around 13 or 14 hours, the long day having their critical day length at the bottom of the flowering range and the short day at the upper limits. In both groups selection must be based upon variability, and variability in time of flowering is likely to come into expression only around the critical flowering point. For that reason selection cannot be made when the plants are grown far below that limit in the case of the short-day plants or far above it in the long-day plants. The critical zone ordinarily shows the spread or amplitude of variation, where only simultaneous flowering would be seen elsewhere.

Many directly practical results helpful to florists and agriculturists throughout the world have followed the recognition of the length-of-day behavior of various plants.

Chrysanthemum growers have forced their crops into earlier flowering by the use of black cloth to exclude light in such a way each day as to shorten the natural daylight period at a time when this is above the critical limit for flowering.

Electric light has been used to supplement the shortened days for the China-aster (*Callistephus*), thus forcing the plants into earlier and more vigorous flowering, the response under such conditions being that of a long-day plant, whereas the chrysanthemum is a short-day type. It would appear, also, that *Calceolaria hybrida, Gaillardia lorenziana, Salpiglossis*, and *Schizanthus* are thus forced by increasing the daily light periods by weak artificial light.

In the Netherlands the ordinary neon light used so extensively in sign advertising at night has been shown to prevent the tendency of greenhouse strawberries to become dormant in wintertime, and it has been used to secure earlier crops.

An understanding of the length-of-day requirements of plants has led to a far better understanding of the successes and failures that hitherto have been observed, but were not readily explained when plants were transported from one region to another that differed more or less in latitude.

English agriculturists have noted that Australian wheats became too early in the latitudes of England and, conversely, the English wheats were unsuited to Australian conditions of day length. They have also learned that English onions bulbing in response to very long days fail to produce good bulbs when grown in the newer African colonies, even though attention has been given to the proper altitudes to secure favorable seasonal temperatures. On the other hand, the Puerto Rican and Bermuda onions grow and bulb well under these African conditions, because they represent strains and varieties stimulated to good bulbing by relatively short days as compared with the very long days of the English summer.

It is known in Europe that the heading of lettuce has specific length-of-day requirements, depending upon the strain or variety. Sharp differences have been found to exist among the various types, as shown by Danish investigators. Some head best under long days, others under shorter days, and these requirements must be understood and given their full expression by suitable lengths of day to secure the best and most practical results with the crop. Bolting or flowering may supervene if too long days are experienced, and, if the days are kept too short, heading may be poor. It would thus seem important to know the optimum range of length of day of each variety so far as heading and other growth expressions are concerned.

There is another phase of the length-of-day problem that has been utilized by breeders and geneticists. In the past, certain plants that may have been different strains, varieties, or species, have been characterized by widely separated flowering seasons because their day-length requirements differed greatly. An understanding of these discrepancies and their basic causes, as associated with a particular length of day, has enabled the breeder to synchronize the time of flowering that otherwise could not have been effected, and, as a result, convenient pollinations and genetic studies were made possible.

An understanding of the length-of-day demands of plants has also enabled the breeder or geneticist to obtain additional generations of plants in a given year in some instances. This has come about by subjecting them to lengths of day above or below the critical limit for optimum flowering, depending upon whether their requirements were for long days or for short days. Before this principle was well understood, it was necessary to await the proper seasonal length of day in some instances, so that only one generation a year could be secured.

With these facts in mind, the length-of-day factor becomes an important one in the commercial growing of crops in and out of season, in various aspects of plant breeding, and in an intelligent guidance to plant distribution over all the world.

SUMMARY

The behavior of a large number of wild and cultivated plants, both native and introduced, and representing many families has been studied under exposures to different constant light periods, in order to learn more concerning the fundamental differences between long-day, short-day, and indeterminate or day-neutral plants in their varied day-length responses.

The daylight exposures ranged from the shortest period of 10 hours, with increases by steps of one-half hour (beginning with 12 hours) up to the full length of day having a maximum of about 15 hours from sunrise to sunset in the latitude of Washington, D. C. For photoperiods of 16 and 18 hours and continuous illumination daylight was supplemented with low intensity illumination from tungsten filament lamps. To obtain light exposures shorter than the full day, the plants were transferred each day to ventilated dark houses for appropriate periods.

The studies have centered mainly on effect of the photoperiod on flowering and the height attained by the plants, though limited observations also were made on various other types and phases of photoperiodic response. The results have been presented chiefly in tabular form. As far as possible the plants have been classed, on the basis of response with respect to flowering, as indeterminate or day neutral, short day, and long day. In some instances the classification is tentative.

Plants that flowered with more or less equal readiness under all light periods used have been placed in the indeterminate group.

Those plants in which flowering is initiated under a given, usually relatively short, day length and appropriate increase in the day length suppresses flowering or causes it to be delayed or less profuse, have been classed as short day.

Plants in which flowering is initiated by exposure to a given, usually relatively long, day length and in which appropriate decrease in day length suppresses flowering or causes it to be delayed or less profuse have been classed as long day.

In a fourth group of plants, flowering is initiated by a zone or band of day lengths of median duration but is inhibited by day lengths either above or below this zone. This group, showing characteristics of both long-day and short-day plants, perhaps may be designated as intermediates. There are few representatives of this group.

In both the long-day and short-day groups there is wide variation in sensitiveness to the day-length factor. Many plants fall within a narrow band of critical day lengths, the long day tending to flower only under photoperiods in excess of this band and the short day only under photoperiods below it. On the other hand, progressive increase in duration of the photoperiod delays or reduces flowering but does not suppress it in certain plants, whereas change of photoperiod in the reverse direction similarly affects still other plants. These two less-sensitive groups have been included in the more typical long-day and short-day classes, respectively.

A knowledge of the photoperiodic responses of plant species and varieties materially simplifies the problem of their successful introduction into new regions.

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