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PHOTOPERIODISM

The Value of Supplementary Illumination and Reduction of Light on Flowering Plants in the Greenhouse

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PHOTOPERIODISM—THE VALUE OF SUPPLEMENTARY ILLUMINATION AND REDUCTION OF LIGHT ON FLOWERING PLANTS IN THE GREENHOUSE

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Although the first record of the effect of light upon plants dates back to 1686 when John Ray in *Historia Plantarum* observed differences due to light variation, it was fully two centuries later before any comprehensive research along this line was undertaken. Since then many of the fundamentals have been established. Wiesner, Siemens, Bailey, Rane, Irons, McArthur, Popp, Denny, Gourley, Nightingale, Tincker, Harvey, Gilbert, Adams, and others may well be included in the list of workers who have been responsible for the recent developments, but the outstanding researches of Garner and Allard have formed the basis of the practical applications reported in this bulletin.

These two workers, by a series of tests, grouped plants into "long day" and "short day" classes dependent upon their light duration and light intensity responses. The results were of particular significance since increasing the duration of the illumination period has consistently resulted in initiating or inhibiting the growth and reproduction of plants, depending upon whether the plants employed normally required long or short days for proper development. In the same manner, the complete exclusion of a portion of daylight during the long days of spring and summer resulted in varying plant reactions. In all cases where positive results were obtained, continuous increase or decrease of light served better than alternate periods of change.

Based upon these premises, a series of tests was conducted to determine the feasibility for commercial greenhouses of increasing the length of day by artificial illumination and the decreasing of the day duration by shading with black cloth. Both methods were to be used in securing earliness of bloom.

TESTS DURING 1930-1931

THE EFFECT OF INCREASING LENGTH OF DAY BY THE USE OF ADDITIONAL LIGHT

To determine the practicability of the use of increased illumination in the greenhouse, a series of tests was started by the senior author at Michigan State College in 1927. These preliminary tests indicated that many crops responded to treatment and that 4 to 5 hours of additional illumination comprised the optimum period necessary. This initial work was conducted with 1000-watt lamps, spaced 5 feet apart at a height of 30 inches over a bench 5 feet wide. Each lamp served to cover an area of 25 square feet. In brief, the results obtained were as follows: Mid-winter flowering snapdragons showed no response, but treatments were successful with spring and summer flowering kinds. Calendulas showed little response to additional light. Sweet peas flowered 2 to 3 weeks earlier than checks, and the mid-winter bud drop was practically eliminated. Carnations produced heavier yields during winter months, although the total for the year was affected but slightly. The most striking results were secured with China Aster (Table 1).

TABLE 1.—Effect of Increased Length of Day on Asters
(Callistephus hortensis)

Variety	Days to maturity		Length of stem		Stems per plant	
	Check	Light	Check	Light	Check	Light
	No.	*No.*	*Inches*	*Inches*	*No.*	*No.*
March crop						
Queen of the Market	100	80	3.5	12	6	12
Crego	100	100	8	19	8	15
November crop						
Queen of the Market	100	86	3.5	8.5	5.5	12
May crop						
Purity	100	90	2	24	9	....
Daybreak	90	85	4	26	8	16
Royal Purple	90	80	5.6	19	7	17
Lavender Gem	95	80	3.5	17.5	9	18

In all instances, the stem length and the rate of production were greater in illuminated plots.

In 1930 this work was resumed at the greenhouse of the Department of Horticulture at Columbus. Instead of using the costly high wattage lamps, 150-watt lamps were installed, spaced 4 feet apart, 18 inches above benches 4 feet in width (Fig. 1). The additional illumination given was for 4 hours, from 6 P. M. to 10 P. M. The costs were calculated on the basis of 3 cents per kilowatt hour.

POT PLANTS

Asparagus sprengeri and *A. plumosus*.—Four-inch plants of each species were placed under 4 hours additional illumination on November 12 and allowed to remain until April 9.

The additional illumination did not increase the number of stems but increased their length (Table 2).

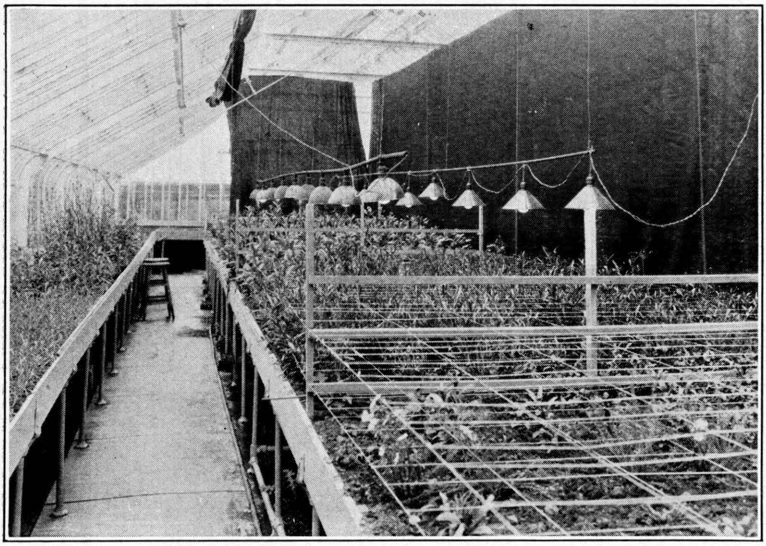

Fig. 1.—Method of applying artificial illumination. (The black shades in the background were used to eliminate the influence of increased illumination on check plots)

Iresene herbsti was placed under experiment from February 13 until April 9. When subjected to additional illumination, a very slight increase in height was recorded.

TABLE 2.—Effect of Increased Length of Day on *Asparagus sprengeri* and *A. plumosus*

	A. sprengeri		*A. plumosus*	
	Average stems	Average stem length	Average stems	Average stem length
	No.	*Inches*	*No.*	*Inches*
Check	11.0	6.4	10.2	6.2
Additional light	11.0	7.2	10.5	8.6

Calceolaria hybrida reacted very favorably to added illumination. A difference of 42 days in earliness was obtained over the check plants (Fig. 2).

Cineraria multiflora and *C. stellata*, receiving 4 hours of additional light, flowered from 8 to 20 days in advance of check plants.

Cyclamen persicum responded to the additional illumination given in late fall from October 16 to December 13. The difference was observed in the earliness of flowers and in the size of the plant. Additional light, applied from February 13 to April 9, on young plants in 2½-inch pots proved beneficial in producing larger plants with more leaves.

Pelargonium zonale (Geranium), subjected to additional light from February 13 to April 9, increased in size of plant. No earliness in flowering was obtained.

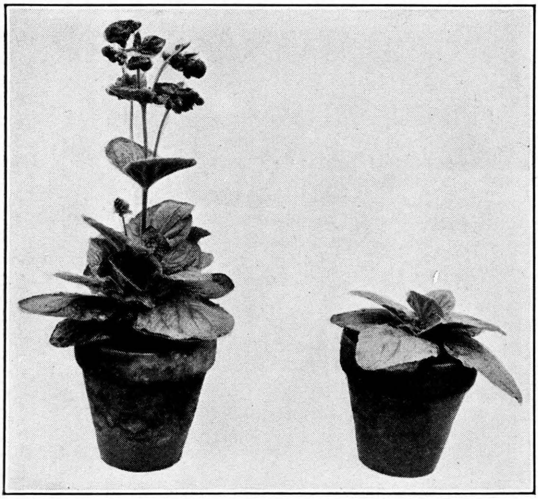

Fig. 2.—*Calceolaria hybrida.* Plant at left received 4 hours additional light for 30 days

Primula obconica responded favorably to the additional illumination treatment received in late fall from October 16 to December 13. The difference observed was in the earliness of flowers and the greater size of the plant.

BULBS, ROOTS, CORMS, AND RHIZOMES

Two varieties of hyacinth, Bismarck and L'Innocence, were given additional light on February 13. No differences in the time of flowering and height of stem were obtained. In the same test, tulips (William Copeland and Clara Butt) and King Alfred *narcissi* were also included, but no appreciable difference was obtained.

Narcissus Tazetta Paper White showed little response to the additional illumination when grown at 50° F. Bulbs were planted in October and placed under test January 8. The check and treated plots flowered January 30; a slight difference in the number of blooms was obtained at the first cutting, but at the end of the test the totals were equal. Narcissus Grand Soliel D'Or, the yellow paper white, was tested in exactly the same manner, and the results were similar to those obtained with the Paper White.

Narcissus poeticus ornatus, placed under test on February 13, flowered March 17. The check plots flowered March 24. An advantage of 7 days was obtained.

Muscari botryoides was placed under treatment December 13, and both the check and the illuminated plots flowered on February 19. The plot receiving additional illumination produced one spike per bulb more than the check plot; the stem length was 1.5 inches longer with additional light.

Iris tingitana, variety Wedgewood, was placed under additional illumination on December 13 and flowered March 2. No difference in time of flowering was noted. Those under added light produced 97 per cent bloom; whereas those in the check plots produced 47 per cent, showing a difference of 50 per cent in favor of additional light. The stem length was 3.5 inches longer as a result of additional light.

Anemone and Ranunculus showed no response to added illumination.

Freesia hybrida, variety Purity, was tested with increased day length. This additional illuminaton was found objectionable because of the reduction in yield without the compensating earliness of bloom.

Zantedeschia aethiopica (Calla lily) plants receiving additional illumination from November 12 to April 9 produced the same number of flowers as the check plants.

Lilium harrissi, L. erabu, L. longiflorum, and *L. longiflorum giganteum* were potted in 5-inch pots in November. Beginning February 7, one plot received additional light; the other remained as a check. Light was discontinued on May 5. Both plots flowered on the same date. A temperature of 50° F. was maintained throughout the growing period and may have been responsible for failure of the plants to respond to additional illumination, since previous tests indicated that, with high temperature, increased day periods produced earliness.

BENCH CROPS

Carnation, variety Matchless, was given additional light, using 100-watt lamps, from November 4 to April 9. The results were as follows:

TABLE 3.—Effect of Increased Daylight Period on Carnations

	Flowers per plant	Average stem length	Average flower diameter
	No.	*Inches*	*Inches*
Light	8.14	19.43	2.52
Check	6.90	18.85	2.53

The increase in production under the additional light was from March 1 to May 15. After that time the check plot gained rapidly in number of flowers. The results show that a slight increase in total production may be expected but that the greatest benefit derived from increased daylight period is earliness. The cost of obtaining the additional 1.24 flowers per plant was 6.4 cents.

ANNUALS

Annuals were sown September 25 and benched December 4. Each plot received 4 hours of additional illumination from the time it was benched. Ten 150-watt lamps illuminated 257 square feet of bench space. They were placed 4 feet apart and 15 inches above the plants and were raised from time to time as the plants grew. The results are given in Table 4.

TABLE 4.—Effect of 4 Hours Additional Illumination on Annuals

Annual plants	Av. flowers per plant		Av. stem length		Date of flowering		Difference in flowering	Cost per sq. ft.	Cost per flower
	Check	Light	Check	Light	Check	Light			
	No.	*No.*	*In.*	*In.*			*Days*	*Cents*	*Cents*
Antirrhinum majus Cheviot Maid....	5.6	3.6	22.9	20.3	Mar. 21	Mar. 6	15	6.5	1.80
Calendula officinalis...............	10.3	9.7	11.2	11.7	Feb. 17	Feb. 17	....	8.8	0.90
Centaurea cyanus..	123.2	76.6	8.3	11.8	Apr. 25	Mar. 17	39	7.2	0.009
Centaurea imperialis.............	16.2	60.4	14.1	12.7	Apr. 23	Apr. 7	16	8.6	0.14
Chrysanthemum coronarium......	20.8	33.0	12.4	11.7	May 9	Apr. 19	20	8.8	0.26
Coreopsis tinctoria	....	....	....	....	May 12	Mar. 21	52	8.8	0.006
Cynoglossum amabile.............	9.1	2.7	13.4	18.4	May 9	Apr. 13	26	8.8	3.10
Delphinium ajacis .	15.0	18.4	23.4	21.2	Apr. 7	Apr. 3	4	8.8	0.47
Didiscus caerulea..	30.6	27.9	9.1	10.1	May 9	Apr. 14	25	8.8	0.31
Iberis umbellata ...	9.3	9.2	19.4	16.5	May 18	Apr. 20	26	8.8	0.90
Matricaria capensis..............	9.7	13.2	28.8	12.1	May 28	Apr. 1	57	8.3	0.62
Salpiglossis sinuata.............	3.8	2.4	35.6	30.0	May 12	Apr. 20	22	8.8	3.60
Scabiosa atropurpurea...........	21.9	45.5	12.0	14.6	June 8	May 6	33	8.8	0.19
Schizanthus pinnatus..............	18.0	14.1	19.5	18.5	Feb. 28	Jan. 28	31	3.4	0.24
Tagetes erecta......	2.5	3.5	7.4	12.2	Apr. 16	Apr. 16	....	8.8	2.50

Additional illumination increased the earliness of the annuals, with the exception of *Calendula officinalis* and *Tagetes erecta*. The practicability of the use of this additional light commercially depends upon the cost. In the tests conducted, the additional expense for the electric current was 3.4 cents per square foot per 30-day month. *Matricaria capensis* (Fig. 3) may be used as an illustration. The additional cost of added light for this crop was 8.3 cents per plant for the entire length of application, and the cost for each individual flowering stem was only 0.6 of a cent. This slight additional expense was more than balanced by the higher price secured, due to the earliness of the crop and its marketing at a time when such flowers are not available under ordinary conditions of culture.

Fig. 3.—*Matricaria capensis* (Feverfew). Plant at right received 4 hours additional illumination

HERBACEOUS PERENNIALS

An increased daylight period (6 P. M. to 10 P. M.) was given to a group of perennials. The plants were removed from the field and placed in a 50° F. house on January 6. Eighteen 75-watt lamps were the source of light, over an area of 200 square feet. Two-year-old field-grown plants were used.

Fig. 4.—A. *Delphinium ajacis*. Plant at right received 4 hours additional illumination. B. *Coreopsis lanceolata*. Plant at right received 4 hours additional illumination

Achillea, Chrysanthemum, Coreopsis (Fig. 4 B), Gaillardia, and Viola responded very satisfactorily to treatment by producing earliness of flowering with an exceedingly small additional cost per flower. No effect was observed with Delphinium (Table 5).

TABLE 5.—Effect of Artificial Light on the Flowering of Herbaceous Perennials

	Av. flowers per plant		Av. stem length		Date of flowering		Difference in flowering	Cost per sq. ft.	Cost per flower
	Check	Light	Check	Light	Check	Light			
	No.	*No.*	*In.*	*In.*			*Days*	*Cents*	*Cents*
Achillea millefolium roseum......	24.1	15.0	19.0	21.9	May 9	Apr. 7	29	7.0	0.46
Chrysanthemum maximum.......	7.4	10.4	15.8	15.5	Apr. 13	Mar. 17	27	5.3	0.50
Coreopsis lanceolata grandiflora..	102.5	146.6	13.0	13.0	May 21	Apr. 20	31	7.0	0.05
Delphinium hybridum	2.2	2.5	22.8	24.1	Apr. 23	Apr. 14	9	7.0	2.80
Gaillardia grandiflora............	8.4	41.2	12.1	13.9	May 11	Apr. 2	39	7.0	0.16
Viola tricolor......	28.7	44.2	....	....	Feb. 20	Feb. 20	....	7.0	0.15

Three separate plantings of Gladiolus corms were made of each variety on October 25, November 15, and December 13. One hundred and fifty-watt lamps were used, and the light was turned on from 6 P. M. to 10 P. M. when the spikes reached a height of 4 inches.

The percentage of plants which flowered is given in Table 6.

TABLE 6.—Effect of Increased Daylight Period upon Gladiolus

Variety	First planting October 25		Second planting November 15		Third planting December 13	
	Check	Light	Check	Light	Check	Light
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Coleman......................	55	95	90	95	35	75
Halley........................	10	20	30	10	90	75
Los Angeles..................	0	77	38	60	....	....
Myrtle.........................	0	70	60	25	50	50
Peachblossom	....	....	205	180	....	....
Pendleton	75	70	95	80	70	40
Sunbeam......................	115	105	115	115	75	110
Virginia.......................	5	75	25	120	55	85

Only three of the eight varieties responded to the additional light treatment. However, in the case of Los Angeles, light was of value since it produced 77 per cent of flowering spikes as compared with complete failure in the check. Coleman and Virginia also responded favorably to additional illumination. In general, the slight increase in production of gladiolus from additional light of low intensity was not sufficient to equal the cost of electricity.

TEMPERATURES

Temperature records were obtained from the area exposed to artificial illumination and from the control plots. The temperature at the soil level was practically the same in each plot with only a slight variation from day to day. Temperature readings recorded 3 inches from the lamp showed a difference of from 3 to 5 degrees Fahrenheit. The temperature taken at the tip of the plants under light was one degree Fahrenheit higher than that of the check plot.

TESTS DURING THE SEASON OF 1931-1932

In a manner similar to the previous season, tests were instituted in the autumn of 1931 and carried out through the spring of 1932.

ANNUALS

To determine the feasibility of forcing annuals during the winter with increased daylight period, the following kinds were set out September 18: *Chrysanthemum segetum* var. Morning Star; *Chrysanthemum purpureum* var. W. E. Gladstone; *Leptosyne maritima; Scabiosa atropurpurea* var. Cherry Red; *Zinnia mexicana;* stock (*Mathiola incana*) var. Lilac Lavender; China Aster (*Callistephus hortensis*) var. Vaughan's Sunshine; *Dimorphotheca aurantiaca; Centaurea suaveolens;* shirley poppy (*Papaver rhoeas*); *Salpiglossis sinuata; Viola tricolor;* and *Gypsophila elegans.* All plants were set 8 x 8 inches, with the exception of stocks which were planted 4 x 8 inches. *Gypsophila elegans* was sown directly into the bench. On December 2, 50 plants of *Chrysanthemum frutescens* (Boston Yellow Daisy) were planted 8 x 8 inches in the vacated space. Four hours of additional light were given the entire space from 6 P. M. to 10 P. M. each day. Eighteen 100-watt bulbs were used to illuminate 200 square feet of bench space. The light was turned on at the time of planting and discontinued at time of flowering.

In Table 7 are given the results of the types that are most profitable to grow in the autumn season.

The table indicates that the illuminated plants came into flower earlier than the checks. Stocks and sunshine asters were among the most outstanding. The cost of the additional light on asters was 0.7 cent per stem. The check did not produce an aster plant over 5 inches in height.

Boston Yellow Daisy produced more flowers and longer stems when grown with a 4-hour period of additional illumination. The lighted plot flowered 19 days in advance of the check plot. The cost per flower for electricity was 0.015 cent.

TABLE 7.—Effect of Light on Fall-planted Annuals Grown During the Winter

Plant material	Av. flowers per plant		Average stem length		Date of flowering		Difference in flowering	Cost per sq. ft.	Cost per flower
	Check	Light	Check	Light	Check	Light			
	No.	*No.*	*In.*	*In.*			*Days*	*Cents*	*Cents*
China Aster (*Callistephus hortensis*) var. Vaughan's Sunshine	*	6.0	*	13.4	*	Dec. 30	*	8.8	0.70
Centaurea suaveolens	*	4.9	*	8.6	*	Nov. 11	*	4.7	0.26
Chrysanthemum frutescens var. Boston Yellow	16.0	20.3	9.3	11.1	Feb. 13	Jan. 25	19	5.7	0.015
Leptosyne maritima	44.1	37.7	13.7	15.5	Jan. 30	Nov. 17	43	16.4	0.24
Stock (*Mathiola incana*) var. Lilac Lavender	One stem per plant		32.3	37.8	Feb. 12	Jan. 14	29	10.1	3.41
Shirley Poppy (*Papaver rhoeas*)	*	10.2	*	9.6	*	Oct. 22	*	2.9	0.16

*Did not flower in check plot.

Erlangea tomentosa and *Felicia amelloides* were tested in the same experiment, but no beneficial results from additional illumination were obtained.

Scabiosa, var. Cherry Red, flowered at Christmas, but the production was not large enough to warrant the additional cost.

LENGTH OF ILLUMINATION

The following experiment was conducted to determine the most desirable length of illumination and light intensity for the plants used. *Centaurea cyanus* and *Statice suworowi* were planted November 2 at a distance of 8 x 8 inches. Four hours of additional illumination, from 6 P. M. to 10 P. M., were given for 30-, 60-, and 90-day periods. Each individual period of time was divided into plots illuminated by 50- and 100-watt lamps (Table 8).

The test with *Statice suworowi* indicated that this plant was not affected by additional illumination. *Centaurea cyanus* (Fig. 5) showed marked effects of various lengths of illumination and intensity. The highest production was obtained when the plants were subjected to 60 days of 4-hour illumination from 100-watt lamps. This treatment produced flowers 66 days in advance of the check. The production was reduced when the number of days of illumination was lowered to 30 days. The stem

TABLE 8.—The Effect of Length of Illumination Period and Intensity of Light on the Life of the Plant

Treatment	Av. flowers per plant Number	Average stem length Inches	Date flowering	Difference in flowering Days	Cost per sq. ft. Cents	Cost per flower Cents
Centaurea cyanus						
Check	26.72	8.5	April 8	....	....	....
30 days, 100-watt	56.60	7.8	Feb. 12	56	4.2	.040
30 days, 50-watt	59.10	7.9	Feb. 5	63	2.1	.021
60 days, 100-watt	143.55	6.2	Feb. 2	66	8.4	.036
60 days, 50-watt	76.05	5.9	Feb. 12	56	4.2	.031
90 days, 100-watt	108.78	6.6	Jan. 25	74	12.6	.070
90 days, 50-watt	89.75	6.2	Feb. 5	63	6.6	.040
Statice suworowi (Russian Statice)						
Check	11.67	12.72	Feb. 13	....	....	....
30 days, 100-watt	11.30	18.60	Feb. 19	....	....	....
30 days, 50-watt	8.50	16.20	Feb. 27	....	....	....
60 days, 100-watt	15.07	17.09	Feb. 12	....	....	....
60 days, 50-watt	11.52	14.74	Feb. 12	....	....	....
90 days, 100-watt	12.42	11.74	Feb. 12	....	....	....
90 days, 50-watt	15.05	14.41	Feb. 12	....	....	....

length was shortened when additional light was applied to *Centaurea cyanus*. This was noticed in every illuminated plot. The plots receiving 30 days of illumination from 50- and 100-watt lamps produced earlier flowers than the check plot but proved that

Fig. 5.—*Centaurea cyanus*. Length of added illumination—4 hours per day. Left to right—Check, 30 days, 60 days, 90 days

TABLE 9.—Time of Applying Artificial Illumination

Treatment	Av. flowers per plant Number	Average stem length Inches	Date of flowering	Difference in flowering Days	Cost per sq. ft. Cents	Cost per flower Cents
Centaurea suaveolens (Fig. 6A)						
Check	19.9	13.1	April 6	....	....	....
Four hours during cloudy days (morning)	31.8	8.8	March 26	11	5.0	0.09
Six hours during cloudy days (morning)	33.8	10.3	April 1	5	6.0	0.11
Four hours, 6 P. M.–10 P. M	17.1	10.0	March 10	27	8.7	0.31
Chrysanthemum purpureum var. W. E. Gladstone						
Check	23.1	15.6	April 14	....	....	....
Four hours, 6 P. M.–10 P. M	31.2	15.5	Feb. 14	50	7.9	0.16
Chrysanthemum segetum var. Morning Star (Fig. 6B)						
Check	19.0	13.2	April 21	....	....	....
Four hours, 6 P. M.–10 P. M	36.4	13.8	Feb. 24	57	7.9	0.12
Clarkia elegan						
Check	8.9	29.0	April 4	....	....	....
Four hours, 6 P. M.–10 P. M	10.3	26.4	Feb. 25	39	7.9	0.48
Delphinium ajacis (Exquisite pink)						
Check	1.3	43.0	May 20	....	....	....
Four hours during cloudy days	11.3	25.4	May 2	18	5.0	0.28
Six hours during cloudy days	12.9	18.4	April 23	27	6.0	0.29
Four hours, 6 P. M.–10 P. M.	11.0	17.0	April 8	43	9.4	0.56
Didiscus caerulea						
Check	31.9	10.2	April 14	....	....	....
Four hours during cloudy days	53.3	9.8	April 6	8	5.0	0.06
Six hours during cloudy days	49.4	11.7	Mar. 29	16	6.0	0.07
Four hours, 6 P. M.–10 P. M.	54.4	9.7	Mar. 7	38	8.7	0.10
Gaillardia lorenziana						
Check	6.5	23.0	May 20	....	....	....
Four hours during cloudy days	33.4	12.9	April 16	35	5.0	0.09
Six hours during cloudy days	30.6	11.3	April 14	37	6.0	0.12
Four hours, 6 P. M.–10 P. M.	38.0	13.0	March 7	75	8.1	0.14
Salpiglossis sinuata						
Check	3.1	21.2	May 6	....	....	....
Four hours during cloudy days	3.5	12.1	April 9	27	5.0	0.89
Six hours during cloudy days	3.0	19.0	April 25	11	6.0	1.26
Four hours, 6 P.M.–10 P. M.	12.7	14.4	Mar. 23	43	7.8	0.39
Schizanthus pinnata						
Check	5.2	13.2	Mar. 4	....	....	....
Four hours, 6 P. M.–10 P. M.	9.9	14.8	Jan. 18	46	4.4	0.27

a longer period of illumination was needed to increase production. The 90-day plots were not equal to the 60-day ones in production, although they were somewhat earlier in flowering. This test indicates, in the case of *Centaurea cyanus*, that a 60-day period of illumination, using 100-watt lamps, may be the most satisfactory.

INCREASING LIGHT INTENSITY DURING CLOUDY WEATHER

Due to the fact that there are a large number of cloudy days in the winter months, experiments were set up to test the practicability of using artificial light to increase the light intensity during these months. Two distinct periods of illumination were tried, one for 4 hours and the other for 6 additional hours. The lights were turned on at 8 A. M. and left on for the full periods, unless the sun appeared, in which case the lamps were turned off and records of the length of illumination were taken. The plants were set 8 x 8 inches on November 23. The lamps were placed 4 feet apart and 15 to 18 inches above the plants. One string of lights was placed over a 4-foot bench.

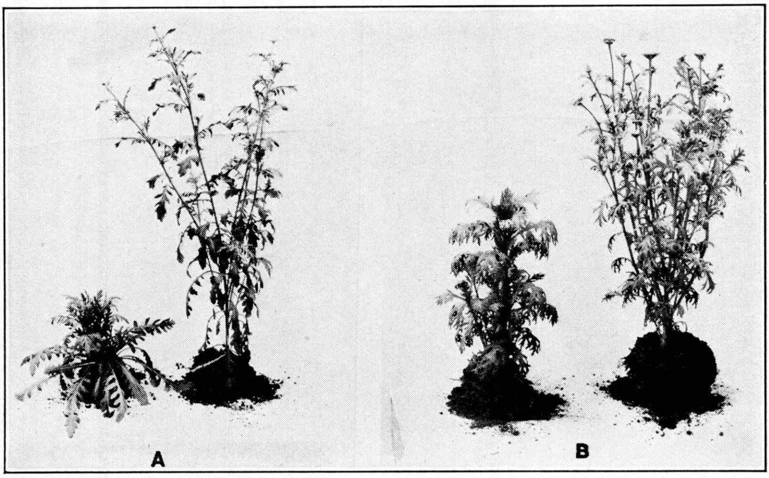

Fig. 6.—A. *Centaurea suaveolens.* **Plant at right received 4 hours of additional illumination. B.** *Chrysanthemum segetum.* **Plant at right received 4 hours of additional illumination per day**

In addition to the above experiments, another test was carried out with similar annuals, receiving 4 hours of illumination from 6 P. M. to 10 P. M. each day. The illumination was from 100-watt lamps. Each lamp illuminated from 10 to 12 square feet of bench space.

In all cases, annuals receiving additional illumination from 6 P. M. to 10 P. M. were much earlier than those receiving additional light during cloudy weather. Chrysanthemum, varieties W. E. Gladstone and Morning Star, flowered 50 and 57 days, respectively, in advance of the check with a cost of 1/8 cent per flower. *Centaurea suaveolens* produced more flowers when additional illumination was used during the day.

The following annuals proved worthless as forcing plants: *Erysimum perofskianum, Ipomopsis elegans,* and *Hunnemannia fumariaefolia.*

PERENNIALS

Perennial clumps were planted in a 50° F. house on December 15. Ten lamps consuming 50 watts each illuminated an area of 100 square feet. Four hours of additional light were used each day from 6 P. M. to 10 P. M. Results are shown in Table 10.

TABLE 10.—The Effect of Increased Daylight Period on Herbaceous Perennials

Plant material	Av. flowers per plant		Average stem length		Date of flowering		Difference in flowering	Cost per sq. ft.	Cost per flower
	Check	Light	Check	Light	Check	Light			
	No.	*No.*	*In.*	*In.*			*Days*	*Cents*	*Cents*
Chrysanthemum maximum	19.7	26.6	10.5	13.0	May 25	Mar. 30	56	5.7	0.13
Coreopsis lanceolata	106.0	102.0	18.0	14.0	May 15	Mar. 30	46	5.7	0.05
Doronicum caucasicum	1.7	1.9	15.6	17.0	Feb. 23	Feb. 16	7	4.1	1.29

Chrysanthemum maximum and *Coreopsis lanceolata* showed marked differences in time of blooming when placed under increased daylight period at a small cost of electricity. *Doronicum* showed a slight response. The following perennials were tried without success: *Aquilegia hybrida, Chrysanthemum coccineum, Delphinium hybridum, Digitalis purpurea, Kniphofia pfitzeriana, Ornithogalum lacteum.*

POT PLANTS

Cineraria cruenta, in 4-inch pots, was given 4 hours of additional illumination from 100-watt lamps from 6 P. M. to 10 P. M. each day, starting November 29 and continuing until January 26. The lighted plants flowered January 26 and the check plants flowered February 20, a difference of 25 days in favor of the illuminated plot.

Freesia, variety Purity, produced shorter stems and less flowers when treated with artificial light from 6 P. M. to 10 P. M. each day. The lighted plot flowered 2 days in advance of the check.

Iris, varieties Wedgewood and Imperator, was planted in 8-inch pots on November 29 and December 20. The first planting was placed under additional light December 9; the second was placed under the treatment January 9. The results are given in Table 11.

TABLE 11.—The Effect of Increased Daylight Period on Iris

Treatment	Wedgewood			Imperator		
	Date of flowering	Per cent flowered		Date of flowering	Per cent flowered	
		Check	Light		Check	Light
Planted Nov. 29. Placed under light Dec. 9	Mar. 3	85.6	87.7	Apr. 4	80.0	94.3
Planted Dec. 20. Placed under light Jan. 9	Mar. 17	81.2	80.4	Apr. 20	93.7	90.0

Light is one of the limiting factors in the early flowering of the bulbous Iris. The Iris requires plenty of space and light to flower well. The slight differences observed in the second planting were due to the greater natural daylight period during March and April which offset the addition of artificial light.

Lilium longiflorum giganteum and *Hydrangea hortensis*.—The use of artificial light on slowly growing lilies is of value. If the lilies do not flower at Easter they are oftentimes worthless. Such lilies were placed under 6 hours of additional illumination from 6 P. M. to 12 P. M., beginning February 18, with a temperature of 60° F. at night and 10 degrees higher in the day time. A similar lot was placed in a temperature that averaged 72° F. at night and 90° F. during the day. A third lot was grown at a temperature of 60° F. at night and 10 degrees higher during the day. This plot was not illuminated and acted as a check. Six 150-watt lamps were placed over 150 lily plants. Each lamp consumed 120 watts, due to a voltage drop in the line (Fig. 7).

The results are shown in Table 12.

Additional heat resulted in shorter stemmed plants than the other two treatments. The date of flowering as the result of additional heat was very close to that from the additional light with only one day's difference. The cost of additional illumination was 3.1 cents per pot.

Since both the additional light and the additional heat produced similar results, the choice of method will depend upon the difference in price and the availability of equipment. Light should be applied at least 2 months before the date that the flowering plants are needed.

Fig. 7.— *Lilium longiflorum.* The effect of additional heat versus additional light. Left—check at 60° F. Center—60° F. and 4 hours of additional illumination. Right—72° F. No illumination

Hydrangea hortensis produced earlier flowers with increased daylight period.

TABLE 12.—The Effect of Additional Illumination on *Lilium longiflorum giganteum*

Treatment	Av. stem length	Av. flowers per bulb	Date of flowering
	In.	*No.*	
Additional heat—72°F	14.3	3.1	March 25
Six hours additional light—60°F	19.3	3.1	March 26
Check—60°F	16.3	3.6	April 10

THE EFFECT OF REDUCED LIGHT

The first experiments with the use of black sateen cloth as a means of shading were started in June 1930. The reduction of the daylight period was accomplished by entirely enclosing chrysanthemum plants with black sateen cloth. The sides and ends were shaded by means of curtains which were attached to wire supports 3½ feet above the bench. The top was covered with portable frames upon which the black sateen cloth was tacked. With this shading, little light was received by the plants (Fig. 8). This method of reducing the length of day was used with Chrysanthemums (varieties Gladys Pearson, Silver Sheen, Rose Perfection, and Golden Glory), *Euphorbia pulcherrima, Stevia serrata, Cyclamen persicum, Primula obconica,* and *Calendula officinalis.*

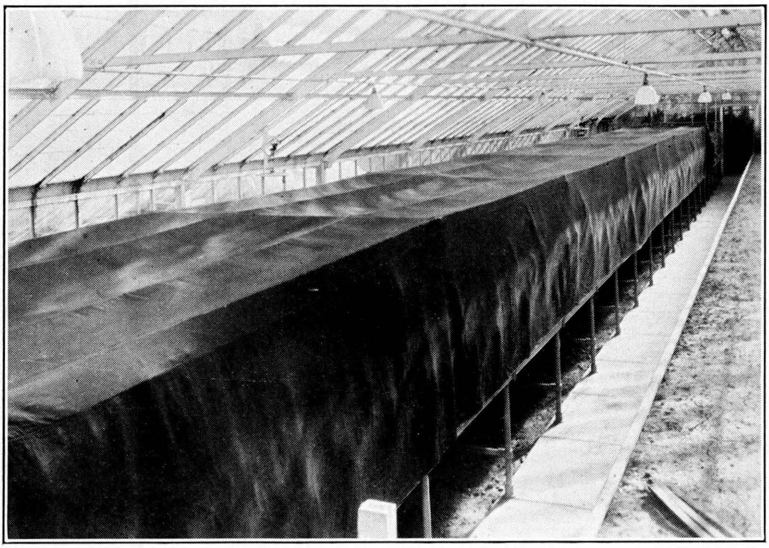

Fig. 8.—Method of applying black sateen shades

The price of application and removal of the shade was very small. Two men put the shades on in the afternoon and removed them in the morning in 15 minutes each.

The plants were set June 16. The varieties used were Golden Glory, Gladys Pearson, Silver Sheen, and Rose Perfection. Five plots were used, consisting of 30 plants of each variety, or 120 plants in each plot. All plants were grown to a single stem. Treatments were as follows:

Plot 1.—Shading started July 26; shades placed in position at 6 P. M. and removed at 7 A. M.

Plot 2.—Check plot; received no shading.

Plot 3.—Shading started June 26, 10 days after planting; shades placed at 6 P. M. and taken off at 7 A. M., reducing day 4 hours.

Plot 4.—Shading started June 26, the same as in Plot 3; shades placed at 5 P. M. and taken off at 7 A. M., reducing day in this way 5 hours.

Plot 5.—Shading started June 26, the same as in Plots 3 and 4; shades placed at 4 P. M. and taken off at 7 A. M., reducing length of day 6 hours.

The shading was discontinued on all plots on September 2. This was due to the fact that the terminal buds were present on all the shaded plots.

TABLE 13.—Effect of Reduced Light upon Chrysanthemums

Plot	Variety	Date of taking terminal bud	Date buds showed color	Date of cutting	Av. length flower stem	Av. diam. of flower	Days cut before check
					In.	*In.*	
1	Golden Glory	Aug. 25	Sept. 8	Sept. 29	35	6	25
	Gladys Pearson	Sept. 3	Sept. 21	Oct. 6	46	6.5	49
	Silver Sheen	Aug. 25	Sept. 6	Sept. 15	31	6	36
	Rose Perfection	Aug. 25	Sept. 6	Sept. 23	36	5.5	38
2 (Check)	Golden Glory	Sept. 10	Oct. 6	Oct. 24	40	5	....
	Gladys Pearson	Oct. 4	Nov. 4	Nov. 24	58	6.25	....
	Silver Sheen	Sept. 10	Oct. 6	Oct. 21	40	5.75	....
	Rose Perfection	Sept. 10	Oct. 13	Oct. 31	42	6	....
3	Golden Glory	July 15	Aug. 23	Sept. 15	24	5.5	39
	Gladys Pearson	Aug. 26	Sept. 15	Oct. 6	44	6	49
	Silver Sheen	July 15	Aug. 14	Sept. 5	20	5.5	46
	Rose Perfection	July 15	Aug. 19	Sept. 5	22	5.25	56
4	Golden Glory	July 21	Aug. 26	Sept. 15	25	5	39
	Gladys Pearson	Sept. 3	Sept. 29	Oct. 13	45	6.25	42
	Silver Sheen	July 21	Aug. 28	Sept. 15	24	5.5	36
	Rose Perfection	July 21	Aug. 28	Sept. 15	27	6	46
5	Golden Glory	July 28	Aug. 28	Sept. 15	27	5.5	39
	Gladys Pearson	Sept. 3	Oct. 4	Oct. 15	45	6.25	40
	Silver Sheen	Aug. 18	Sept. 1	Sept. 15	28	6	36
	Rose Perfection	Sept. 2	Sept. 15	Sept. 29	38	6	32

Shading brought the chrysanthemum into flower 22 to 56 days earlier than the check which received no shading. The diameter of the flower was as large as, and in some cases larger than, the check. Shading resulted in shorter stems, but they were sufficiently long to make the flowers salable (Table 13). The decrease in stem length may be accounted for by the fact that the plants under the shade did not form any crown buds but produced terminal buds instead.

TESTS IN 1931

The cultural practices used approximated those of the commercial growers. Plants were set at a distance of 8 inches by 8 inches on June 15. These plants were all pinched on June 23. Standards were grown to two stems per plant, disbuds to five stems, and on pompons all shoots were allowed to mature. The soil was of a compost nature, and 10 pounds of superphosphate per 100 square feet were applied before planting.

In this experiment the following tests were carried out:

(1) Value of white cloth as compared to black.
(2) Time of applying shade during the day.
(3) The effect of nitrogen and potassium fertilizers on the date of flowering.
(4) Intensity of light as compared with the duration. (In all these series, four types of shade were used):
  (a) Complete shading with black sateen cloth.
  (b) Overhead shading with black sateen cloth, the sides exposed.
  (c) Entire shading with white sateen cloth.
  (d) Overhead shading with white sateen cloth, the sides exposed.

Each type of shade included six plots, with 30 plants to the plot. The treatments were as follows:

Plot 1.—Shades were applied at 6 P. M. and removed at 7 A. M. Nitrogen was applied weekly from time of planting until color of flower appeared.

Plot 2.—Shades were applied at 6 P. M. and removed at 7 A. M. Nitrogen was applied weekly after terminal bud appeared until flower bud showed color.

Plot 3.—Shades were applied at 6 P. M. and removed at 7 A. M. Potash was applied bi-monthly from date of planting until flower bud showed color.

Plot 4.—Shades were applied at 6 P. M. and removed at 7 A. M. No additional treatment.

Plot 5.—Shades were applied at 4 P. M. and removed at 7 A. M. No additional treatment.

Plot 6.—No light treatment.

Nitrogen was applied as ammonium sulfate at the rate of 2 pounds per 100 square feet of bench space. Potassium chloride was applied at the rate of 1 pound per 100 square feet of bench space.

THE TIME OF APPLICATION FROM DATE OF PLANTING

Richmond and Snow White, two mid-season standards, and two mid-season pompons, White Wings and Ida, were used in this test.

Plot 1.—Pompons. Shade applied 4 weeks after planting, July 16.

Plot 2.—Standards, Richmond and Snow White. Shading applied 4 weeks after planting, July 16.

Plot 3.—Standards, Richmond and Snow White. Shade applied 6 weeks after planting, July 29.

Plot 4.—This test included 35 varieties of the standard and disbud type. The first portion received shade from July 16 to August 16; the second portion received shade from August 17 to September 9.

WHITE SHADES VERSUS BLACK SHADES

Entire white shades did not result in earliness. Overhead black, as well as overhead white shades did not cut down the intensity of daylight sufficiently to hasten blossoming. Plots shaded with entire white shades for 4 weeks and followed with entire black shades showed a marked advantage in time of flowering over check. Complete shading with black shades was found to be the most satisfactory method (Fig. 9).

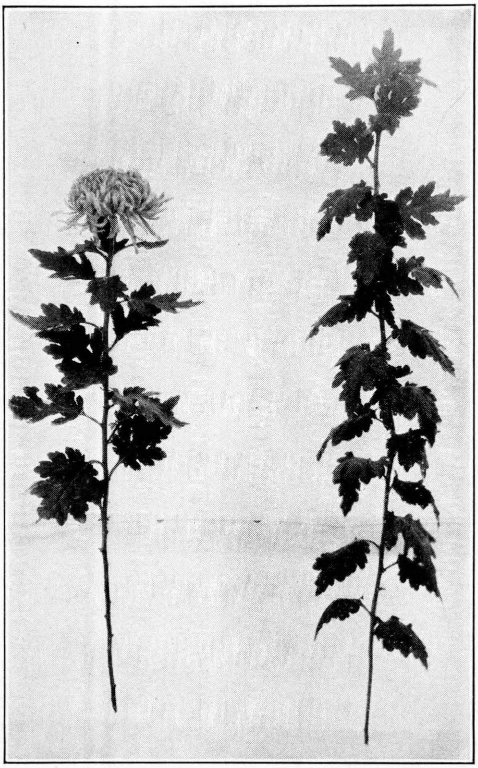

Fig. 9.—Shaded versus unshaded. Chrysanthemum Silver Sheen. Left—Shaded. Right—Normal day length

The differences obtained when entire black shades followed entire white shades may be attributed fully to the black shades. The latter shade was applied August 27, fully 10 weeks after planting. Up to that date white shades were used on plots designated. The results show that shading in the latter stages of plant growth has some beneficial effect, Table 14.

In the case of pompons, overhead black shades showed a marked difference over the check, but this earliness was only obtained on the plants grown in the center of the bench. The plants on the outer portion of the bench were not affected by the treatment.

TABLE 14.—Effect of Various Methods of Shading on Time of Blossoming

Type of shade	Series 1		Series 2		Series 3	
	Shades applied 4 weeks after planting		Shades applied 4 weeks after planting		Shades applied 6 weeks after planting	
	Difference in days					
	White Wings	Ida	Rich-mond	Snow White	Rich-mond	Snow White
Entire black shades	35	6	24	19	24	19
Overhead black shades	26	6	0	0	0	0
Entire white shades	0	0	0	0	0	0
Entire white shades (4 weeks) followed with entire black shades	8	6	9	11	9	9
Overhead white shades	0	0	0	0	1	0
Check	0	0	0	0	0	0

Duration of light, rather than the intensity of light, governs the reaction of the chrysanthemum to earlier flowering. Lath-covered frames which cut the intensity from 60 per cent to 75 per cent had no beneficial effect upon the time of flowering. Low light intensities weakened the plant. With the use of white cloth the light intensity was low; yet the time of flowering was not hastened.

FERTILIZER APPLICATIONS IN CONJUNCTION WITH REDUCED DAYLIGHT

Auchter and Harley (11) reported that lack of nitrates in the nutrient solution delayed blossoming of the pepper decidedly, in spite of the length of day. The addition of nitrates did not influence the time of blossoming in soybeans exposed to the same length of day. This was explained by the fact that soybeans are legumes, and so the checks utilized the nitrates they manufactured. They state: "Results suggest that the different responses obtained when the plants were subjected to different lengths of day might be caused by modifying their nutritional condition."

Garner, Allard, and Bacon (42) found that the action of light produces an influence on the acidity relations in plants. In the case of short-day plants, upward elongation of the stem is a characteristic response to a relatively long daily illumination period and is associated with an increase in the active acidity of the plant, particularly near the growing point. Where elongation is hindered, acidity remains at a low level.

Tincker (100) stated: "It would seem that the length of day influences the elongation of the stem and controls the utilization of the products of photosynthesis. By this means the carbohydrate nitrogen ratio of the tissues is influenced, and in general, there would appear to be a correlation between the carbohydrate nitrogen ratio and the behavior of the plant. This does not necessarily signify that the magnitude of the ratio determines the behavior of the plant and the nature of the growth made—the reverse may equally well be the true interpretation of the facts."

Nightingale (77), working with salvia, buckwheat, and soybean, found that plants illuminated for 7 hours each day had a higher percentage of nitrates and carbohydrates than long-day plants. He considered that carbohydrates accumulated in the short-day plants, presumably because there is relatively little utilization of them in the changes of nitrates to other forms of nitrogen. Gilbert (43, 44) supports Nightingale's conclusions.

Arthur (9) reported that flowering in radish is independent of the carbohydrate nitrogen relations and depends only upon day length.

Deats (26) suggested that the relative length of day and night may operate by influencing the carbohydrate nitrogen relationship.

To determine the effect of fertilizers on the time of flowering of chrysanthemum with reduced daylight, a series of plots was set up.

Data show that no difference in time of flowering was obtained when nitrogenous and potassium fertilizers were applied. Stem length and flower diameter varied somewhat in favor of the non-fertilized plots (Table 15). Microchemical tests for nitrates, starch, and reducing sugars were made September 9 on all plots in Table 15. Tests were made at the tip, mid-section, and base of the stem.

Plots 1 and 2, both receiving nitrogen, showed very high amounts of nitrates in all tissues of the stem. The largest amount of nitrates was found in the mid-section of the stem. The same plants showed very small traces of starch at the base of the stem. Reducing sugars were present in very small amounts in the phloem at the mid-section and tip of the stem.

Plot 3, receiving muriate of potash, showed small amounts of starch in the mid-section of the stem; traces of reducing sugars were present in the tip and mid-section. Nitrates were abundant in the stem, especially in the xylem and pith. Plots 1 and 2 showed the presence of the largest amount of nitrates in top, mid-, and basal sections of the stem.

TABLE 15.—The Effect of Nitrogenous and Potassium Fertilizers on the Time of Flowering of Chrysanthemum

Shading applied July 16 and removed August 17

	First appearance of bud	Date bud showed color	Date of cutting	Av. length stem	Av. diameter flower
Plot 1				*In.*	*In.*
(N weekly from time of planting)					
Richmond	Aug. 6	Sept. 8	Sept. 29	21	5.3
Snow White	Aug. 7	Sept. 27	Oct. 16	21	5.0
Plot 2					
(N when terminal bud appeared)					
Richmond	Aug. 6	Sept. 8	Sept. 29	21	5.3
Snow White	Aug. 7	Sept. 22	Oct. 16	22	5.0
Plot 3					
(K bi-monthly)					
Richmond	Aug. 6	Sept. 8	Sept. 29	20	5.5
Snow White	Aug. 7	Sept. 22	Oct. 16	24	5.0
Plot 4					
(No fertilizer)					
Richmond	Aug. 6	Sept. 8	Sept. 29	21	5.7
Snow White	Aug. 7	Sept. 22	Oct. 16	24	5.0
Plot 5					
(No fertilizer)					
Richmond	Aug. 6	Sept. 8	Sept. 29	20	5.7
Snow White	Aug. 7	Sept. 22	Oct. 16	26	5.0
Check					
(No shading, no fertilizer)					
Richmond	Sept. 11	Oct. 12	Oct. 23	42	6.0
Snow White	Sept. 11	Oct. 19	Nov. 4	40	6.0

Results of tests on plants in Plots 4 (receiving no fertilizer and bud shaded from 6 P. M. until 7 A. M.) and 5 (receiving no fertilizer but shaded from 4 P. M. until 7 A. M.) were identical. No starch was present, but traces of reducing sugars were found in all sections of the stem. Nitrates were abundant in the pith. Nitrates were as abundant in Plots 4 and 5 as in Plot 3 which received potassium bi-monthly and was shaded from 6 P. M. to 7 A. M.

Plot 6, unshaded and unfertilized, was higher in starch than the other plots; the nitrates in this plot compared favorably with the amounts found in Plots 3, 4, and 5. Reducing sugars were present in larger quantities in this plot than in the other plots. The largest amount was found in the mid-section and tip of the stem. These microchemical tests, as well as the general appearance of the plants studied, failed to show any correlation between reduction of daylight period and addition of nitrogen and potassium.

TIME OF APPLICATION OF SHADE

Previous tests showed that chrysanthemums responded to an 11-hour day and produced slightly better flowers than those grown under shorter days. A further study was made with the 10-hour day, as compared with the 11-hour day, but no difference could be determined. The slight variations obtained were insignificant.

VARIETY TEST

Thirty-five varieties of standards and disbud pompons were arranged in several plots. One plot was shaded from July 16 to August 16. The second plot received shade from August 17 to September 9. Entire black shade was used. In addition to these varieties, Yoder Brothers, Barberton, Ohio, and R .W. Rowe, Kirkwood, Missouri, carried out similar tests using both pompons and standards. Shade was applied July 21 at Yoder's and July 15 at Rowe's. Table 16 shows the effect of shade on a large number of varieties (Fig. 10).

Fig. 10.—Gold Lode Chrysanthemum after shading. In bloom, September 5. Normal flowering time, October 1

TABLE 16.—Effect of Shading Chrysanthemum Varieties

Variety	Date of normal flowering	Date of shading	Date of taking terminal bud	Date of cutting	Results	Remarks
Alecia........	Oct. 31	July 21	....	Sept. 29	Fair	Color fades.
Aloma........	Oct. 25	July 21	....	Sept. 24	Poor	Poor development of flowers.
Angelo	Oct. 25	July 21	....	Sept. 22	Poor	Might be improved by disbudding.
Ball of Gold...	Nov. 5	July 16	Aug. 19	Nov. 8	Fair	Not any earlier than normal.
Ball of Gold...	....	Aug. 17	Sept. 8	Oct. 21	Good	....
Bellingham ...	Nov. 1	July 16	Aug. 19	Oct. 14	Poor	....
Bellingham ...	....	Aug. 17	Sept. 8	Oct. 12	Fair	....
Berneita.......	Oct. 25	July 16	Oct. 19	Oct. 12	Good	....
Berneita.......	....	Aug. 17	Sept. 8	Oct. 12	Good	....
Betsy Ross	Nov. 15	Aug. 17	....	Oct. 10	Good	....
Betty Price....	Nov. 25	July 1	....	Nov. 5	Good	....
Bronze Cup....	Nov. 10	July 16	Sept. 3	Nov. 4	Poor	....
Bronze Cup....	....	Aug. 17	Sept. 8	Oct. 16	Poor	....
Bronze Queen..	Oct. 5	July 21	....	Sept. 26	Fair	....
Calumet.......	Oct. 20	July 16	Aug. 16	Oct. 9	Good	Equally as good in early as late shading.
Calumet......	....	Aug. 17	Sept. 3	Oct. 9	Good	....
Camilla	Oct. 20	July 21	Aug. 6-12	Sept. 21	Fair	....
Captain Cook .	Nov. 1	July 21	....	Sept. 25	Good	....
Celebration....	Nov. 21	July 16	Aug. 19	Oct. 21	Fair	Do not take first bud.
Celebration ...	....	Aug. 17	Sept. 11	Oct. 21	Fair	....
Celestra.......	Oct. 15	July 16	Aug. 12	Sept. 18	Poor	Very short stems.
Celestra......	....	July 21	Aug. 5-10	Sept. 8	Good	....
Celestra......	....	July 1	July 25	Sept. 10	Extra good	....
Celestra......	....	Aug. 17	Sept. 3	Sept. 29	Good	....
Cherokee	Oct. 31	July 16	Sept. 11	Nov. 4	Poor	Take late bud.
Cherokee	....	Aug. 17	Sept. 11	Oct. 26	Fair	Much better on later buds.
Chicago Pearl.	Nov. 20	July 1	....	Nov. 1-15	Good	....
Clara B. Ford.	Nov. 20	July 1	Aug. 5	Oct. 1	Good	....
Cora Peck Buh	Oct. 25	Aug. 21	....	Sept. 24	Poor	Lack of uniformity in maturity.
Dainty Maid ..	Nov. 1	Aug. 21	....	Oct. 5-7	Poor	Lack of uniformity in maturity.
Dr. Enguehart	Thanksgiving	Aug. 16	Sept. 13	Nov. 10	Good	....
Dr. Enguehart	....	July 16	Aug. 10	Oct. 20	Fair	....
Dr. Enguehart	....	Aug. 17	Sept. 19	Nov. 7	Good	....
Early Monarch	Oct. 10	July 1	Aug. 1	Oct. 1	Poor	....
Ethel..........	Oct. 25	July 21	....	Sept. 28	Good	Color fades to yellow.
Firebird.......	Oct. 31	July 21	....	Sept. 24	Poor	Poor development of flowers.
Gladys Pearson	Nov. 25	July 1	Aug. 10	Oct. 1-30	Fair	....
Gladys Pearson	....	July 16	Sept. 11	Nov. 10	Good	Color fades.
Gladys Pearson	....	Aug. 17	Sept. 15	Oct. 27	Good	Color fades.
Golden Bronze.	Oct. 15	July 21	Aug. 6-10	Sept. 11	Poor	Too soft, color fades.
Golden Climax	Nov. 20	July 1	....	Nov. 1-10	Fair	....
Golden Glory ..	Oct. 25	July 16	Aug. 16	Oct. 5	Fair	Will do well under early shading.
Golden Glory .	....	Aug. 17	Sept. 3	Oct. 16	Fair	....
Golden State ..	Nov. 1	July 16	Aug. 31	Oct. 12	Fair	Stems short.
Golden State ..	....	Aug. 17	Sept. 8	Oct. 21	Good	Good stem length.
Golden Wave ..	Oct. 20	July 16	Aug. 19	Oct. 8	Poor	Small flowers, short stems.
Golden Wave ..	....	Aug. 17	Sept. 3	Oct. 12	Fair	....
Gold Lode	Oct. 1	July 1	July 25	Sept. 5	Good	Burned from heat.
Gold Lode	....	July 21	Aug. 5-9	Sept. 2	Poor	Too soft.
Gold Mine	Oct. 25	July 21	....	Oct. 5-7	Poor	Lack of uniformity in maturity.
Greta..........	Oct. 20	July 21	....	Oct. 16	Good	....
Gretchen Piper	Oct. 25	July 21	....	Sept. 28	Poor	Poor development of flowers.
Harvard	Nov. 15	July 16	Sept. 3	....	....	Buds did not open.
Harvard	....	Aug. 17	Sept. 8	Oct. 16	Fair	Poor variety.
Hilda Bergen..	Oct. 31	July 16	Aug. 19	Oct. 9	Fair	....
Hilda Bergen..	....	Aug. 17	Sept. 3	Oct. 9	Good	Much better under late shading.
Ida	Oct. 15	July 21	....	Sept. 22	Good	....
Indianola.....	Oct. 10	July 16	Aug. 10	Sept. 18	Good	Best early.
Indianola.....	....	July 21	Aug. 6-10	Sept. 11	Good	....
Indianola......	....	Aug. 17	Sept. 3	Oct. 2	Good	....
Irene	Oct. 20	July 21	....	Sept. 16	Good	....
Iridescent	Oct. 15	July 21	....	Sept. 25	Fair	Flowers fade.
Josephine Foley	Nov. 1	July 16	Aug. 19	Oct. 16	Poor	Short stems.
Josephine Foley	....	Aug. 17	Sept. 8	Oct. 16	Fair	Crooked stems.
La France.....	Oct. 28	July 16	Aug. 19	Oct. 23	Poor	....

TABLE 16.—Effect of Shading Chrysanthemum Varieties—Continued

Variety	Date of normal flowering	Date of shading	Date of taking terminal buds	Date of cutting	Results	Remarks
La France	....	Aug. 17	Sept. 8	Oct. 31	Fair	Color good.
Leila	Oct. 15	July 1	....	Oct. 5	Good	....
Leila	....	July 21	....	Sept. 28	Poor	Flowers fade.
Lilac	Oct. 15	July 1	....	Oct. 5	Good	....
Lilac	....	July 21	....	Sept. 23	Fair	....
Lillian Doty	Nov. 1	July 21	....	Sept. 28	Poor	....
Marie DePetris	Nov. 20	July 16	Sept. 15	....	....	Plants poor at start.
Marie DePetris	....	Aug. 17	Sept. 15	Nov. 7	Good	....
Mefo	Nov. 15	July 15	Aug. 19	Oct. 12	Good	....
Minong	Oct. 25	July 1	....	Oct. 1	Good	....
Minong	....	July 21	....	Sept. 21	Fair	....
Mintje	Oct. 18	July 21	....	Sept. 21	Poor	Lack of uniformity in maturity.
Mrs. Alex Laurie	Nov. 15	July 16	Aug. 19	Nov. 4	Fair	Color fades on early buds.
Mrs. Alex Laurie	....	Aug. 17	Sept. 6	Oct. 26	Fair	Color fades.
Mrs. H. E. Kidder	Oct. 15	July 16	Aug. 19	Oct. 9	Good	....
Mrs. H. E. Kidder	....	July 21	Aug. 6-10	Sept. 15	Good	....
Mrs. H. E. Kidder	....	Aug. 17	Sept. 3	Oct. 9	Good	....
Mrs. N. T. Ross	Nov. 25	July 16	Sept. 11	Nov. 6	Poor	Short, poorly developed flowers.
Mrs. N. T. Ross	....	Aug. 17	Sept. 11	Oct. 21	Good	....
Mrs. R. N. Calkins	Nov. 25	July 16	Sept. 11	....	....	....
Mrs. R. N. Calkins	....	Aug. 17	Sept. 11	Nov. 7	Good	....
Mrs. Walter Engel	Nov. 25	July 16	Sept. 11	Nov. 7	Fair	....
Mrs. Walter Engel	....	Aug. 17	Sept. 11	Oct. 26	Good	....
My Pride	Oct. 25	July 21	....	Sept. 28	Poor	Lack of uniformity in maturity.
Muskoko	Nov. 10	July 16	Aug. 19	Oct. 10	Good	....
Muskoko	....	Aug. 17	Sept. 8	Oct. 12	Good	....
New York	Nov. 25	July 1	....	Nov. 1	Good	....
Nubian	Oct. 15	July 21	....	Sept. 23	Fair	Flowers fade.
Norma	Nov. 15	July 1	....	Oct. 12-30	Good	....
Nuggets	Nov. 1	July 21	....	Sept. 28	Poor	Lack of uniformity in maturity.
October Frost	Oct. 15	July 16	Aug. 16	Sept. 28	Poor	Very poor variety.
October Frost	....	Aug. 17	Sept. 3	Oct. 9	Poor	....
October Rose	Oct. 20	July 16	Aug. 12	Sept. 16	Fair	Color fades.
October Rose	....	July 21	Aug. 5-10	Sept. 18	Fair	Color fades.
October Rose	....	July 1	July 25	Oct. 1	Poor	....
October Rose	....	Aug. 17	Sept. 3	Oct. 9	Good	....
Pink Dot	Oct. 25	July 1	....	Oct. 5	Good	....
Pink Dot	....	July 21	....	Sept. 27	Good	Color fades.
Pink Chieftain	Nov. 1	July 1	Aug. 1	Oct. 1	Extra good	....
Quaker Maid	Oct. 15	July 16	Aug. 14	Sept. 18	Fair	Small flowers.
Quaker Maid	....	July 1	July 25	Sept. 5	Good	Burned by heat.
Quaker Maid	....	July 21	Aug. 5-10	Sept. 2-14	Poor	Too soft.
Quaker Maid	....	Aug. 17	Sept. 3	Sept. 28	Fair	Small flowers.
Richmond	Nov. 1	July 16	Aug. 12	Sept. 29	Fair	Short stems.
Richmond	....	July 29	Aug. 27	Sept. 29	Good	....
Rose Charm	Oct. 26	July 1	....	Oct. 20	Poor	....
Rose Glory	Oct. 15	July 21	Aug. 6-12	Sept. 4	Good	....
Rose Marie	Oct. 20	July 16	Aug. 16	Sept. 15	Poor	....
Rose Marie	....	July 21	Aug. 6-12	Sept. 8	Poor	....
Rose Marie	....	Aug. 17	Sept. 3	Sept. 28	Poor	....
Rodell	Oct. 20	July 21	....	Sept. 19	Good	....
Silver Sheen	Oct. 20	July 16	Aug. 13	Sept. 28	Good	....
Silver Sheen	....	July 21	Aug. 6-12	Sept. 11	Good	....
Silver Sheen	....	Aug. 17	Sept. 3	Oct. 2	Good	....
Sheila	Oct. 30	July 21	....	Sept. 25	Good	....
Snow White	Oct. 30	July 16	Aug. 16	Oct. 16	Fair	Short stems.
Snow White	....	July 29	Aug. 27	Oct. 20	Good	....
Stop-light	Nov. 10	July 16	Sept. 12	Nov. 6	Poor	....
Stop-light	....	Aug. 17	Sept. 12	Oct. 23	Fair	....
Sun Glow	Oct. 25	July 1	Aug. 1	Oct. 1	Extra good	....
Thanksgiving Pink	Nov. 25	July 16	Sept. 11	Nov. 10	Good	....
Thanksgiving Pink	....	Aug. 17	Sept. 11	Nov. 10	Good	....
Tom Browne	Nov. 25	July 16	Sept. 3	....	Poor	Poor variety.

TABLE 16.—Effect of Shading Chrysanthemum Varieties—Concluded

Variety	Date of normal flowering	Date of shading	Date of taking terminal buds	Date of cutting	Results	Remarks
Tom Browne ..	....	Aug. 17	Sept. 8	Nov. 9	Poor	....
Western Beauty	Nov. 25	July 1	....	Oct. 30	Good	....
White Chieftain	Nov. 1	July 1	Aug. 1	Oct. 1	Extra good	....
Whittier.....	Nov. 20	July 1	Aug. 10	Oct. 1	Fair	....
Yellow Fellow..	Nov. 15	July 1	....	Nov. 5	Good	....

Calendula officinalis.—Seed was sown the early part of August. Plants were bedded September 9. Forty plants of each variety were under normal treatment; 30 plants of each variety made up the treated plot. The shade was applied on the same date and discontinued November 10, because the plants were weakened and continuation of shading would have resulted in death.

The results show that shading the Calendula for a portion of the day retarded flowering. The yield was much lower as long as the shade was applied, but, after its removal, the plants recuperated very rapidly. The flower diameter was slightly larger under the shaded plots, but the stem length was reduced, Table 17.

TABLE 17.—The Effect of Shade on Calendula

Variety	Flowers cut to Nov. 18		Total flowers		Av. flowers per plant		Av. stem length		Av. flower diameter	
	Check	Shade	Check	Shade	Check	Shade	Check	Shade	Check	Shade
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*In.*	*In.*	*In.*	*In.*
Ball's Gold	64	40	167	136	4.18	4.53	16.0	15.4	2.8	2.9
Ball's Orange	125	39	198	101	4.95	3.37	13.2	11.6	2.4	2.5

Stevia serrata.—(a) Field-grown plants were planted into the bench at a distance of 12 x 12 inches on September 5, 1930. Shading was started at once, applying the shade at 3 P. M. and removing it at 7 A. M. each day. The shading was continued until October 15, when the buds appeared. Twenty plants were grown in each plot.

Table 18 gives data showing the effect of shading Stevia. The average stem length was reduced somewhat but not to any appreciable extent. The advance of 32 days in time of blossoming under shade was significant and points to an important commercial practice.

TABLE 18.—The Effect of Reduced Daylight Period on *Stevia serrata* (1930)

	First appearance of buds	First appearance of color	Full flower	Difference in flowering	Av. flowers per stalk	Av. stem length
				Days	*No.*	*In.*
Shaded	Oct. 8	Oct. 25	Nov. 15	32	801	44
Check	Nov. 12	Nov. 21	Dec. 18	....	833	49

Another shading test with Stevia was made later in the season to determine the effects of late-season shading. This shade was applied similarly to that used in the former test. Shade was first applied October 28 and was discontinued November 18. At this date it was evident that no difference would be obtained. The length of day at this stage may have caused flower bud formation before shade application so that no artificial means of shortening the day proved helpful. Plants under both conditions were similar in habit of growth.

A similar experiment was conducted in 1931 with 25 plants to the plot. Plants were set in the bench on August 27. Black sateen cloth was applied each day from 4 P. M. to 7 A. M., starting September 18 and concluding October 13 (Table 19).

TABLE 19.—The Effect of Reduced Daylight Period on *Stevia serrata* (1931)

	First appearance of buds	Date flower showed color	Date cut	Difference in flowering	Average stem length
				Days	*In.*
Shade	Oct. 13	Nov. 4	Nov. 24	6	53
Check	Oct. 21	Nov. 15	Nov. 30	....	57

Reducing the daylight period did not show so great a difference in 1931 as in 1930. Extreme heat during this season naturally hastened normal development so that marked differences could not be obtained.

Euphorbia pulcherrima.—Plants from 3-inch pots were shifted to 5-inch pots on September 24. Thirty-three plants were

TABLE 20.—The Effect of Reduced Daylight Period on *Euphorbia pulcherrima*

	First appearance of bracts	First appearance of flowers	Full flower	Average stem length
				In.
Check	Nov. 7	Nov. 10	Dec. 15	18.5
Shade	Oct. 25	Oct. 28	Nov. 30	17.0

grown in each plot. One portion was grown in the normal day; the other was shaded from 3 P. M. to 7 A. M. each day.

The poinsettia developed colored bracts and flowers about 2 weeks earlier with reduced day length (Table 20).

Primula obconica.—Due to the fact that this plant flowers during the short winter days, tests were conducted to determine the practicability of the reduction of length of day. The experiment was started September 5 and continued to October 16. Plants grown in the normal length of day flowered and produced larger plants than those grown under the shaded plot.

Cyclamen persicum.—Cyclamen in 5-inch pots were grown in reduced length of day. The plants were shaded September 5 to October 16. The results were similar to those obtained with *Primula obconica.* Smaller plants and fewer numbers of flowers per plant resulted when length of day was reduced.

CLASSIFICATION OF LONG- AND SHORT-DAY PLANTS TESTED IN EXPERIMENTS

SHORT-DAY PLANTS

Chrysanthemum (*indicum* x *morifolium*)
Euphorbia pulcherrima
Freesia hybrida
Stevia serrata

LONG-DAY PLANTS

Achillea millifolia rosea
Antirrhinum majus
Calendula officinalis
Calceolaria hybrida
Callistephus hortensis (Sunshine)
Centaurea cyanus
Centaurea imperialis
Centaurea suaveolens
Chrysanthemum coccineum
Chrysanthemum coronarium
Chrysanthemum maximum
Chrysanthemum purpureum
Chrysanthemum segetum
Cineraria multiflora
Cineraria stellata
Coreopsis grandiflora
Coreopsis tinctoria
Cynoglossum amabile
Didiscus caerulea
Dimorphotheca aurantiaca
Delphinium ajacis
Delphinium hybridum
Gaillardia grandiflora
Gladiolus
Gypsophila elegans
Hunnemannia fumariaefolia
Hydrangea hortensis
Iberis umbellata
Ipomopsis elegans
Iris tingitana
Leptosyne maritima
Mathiola incana
Matricaria capensis
Papaver rhoeas
Salpiglossis sinuata
Scabiosa atropurpurea
Schizanthus pinnatus

NOT SENSITIVE TO LENGTH OF DAY

Asparagus plumosus
Asparagus sprengeri
Achyranthes brilliantissima
Cyclamen persicum
Dianthus caryophyllus
Digitalis purpurea
Erlangea tomentosa
Erysinum perofskianum
Hyacinthus orientalis
Ixia maculata
Kniphofia pfitzeriana
Lilium longiflorum harrisii
Lilium longiflorum erabu
Lilium longiflorum giganteum
Linum perenne
Muscari botryoides
Narcissus pseudonarcissus
Narcissus poeticus
Narcissus tazetta
Ornithogalum lacteum
Primula obconica
Pelargonium zonale
Tagetes erecta
Tulipa gesneriana hybrids
Viola tricolor
Zantedeschia aethiopica
Zinnia mexicana

DISCUSSION

The duration of light is the limiting factor in the flowering of long-day plants in the winter months. Annuals, such as Matricaria and Centaurea, remain in the rosette condition when they are grown under normal light conditions during the winter months. With the addition of low-intensity electric light from 100-watt clear glass lamps for 4 hours each day, elongation and flowering occurred.

Tincker (102) reported that light of low intensity can bring about a decided change in the habit of growth. With the long periods of light, many plants continue to elongate, producing leaves and flowers.

Most investigators of the effects of additional illumination used high wattage lamps. Weinard and Decker (109), using 500-watt lamps, reported that corms of Gladiolus, variety Virginia, planted in the greenhouse in October bloomed 10 days earlier than did the controls under normal light and produced more than twice as many blooms. The factor of heat may have played its part in the results secured by these workers.

With the use of 100-watt lamps on Gladiolus no great differences in time of flowering were obtained, although some variations in production were secured with certain varieties.

Tjebbes and Uphof (104) reported that they hastened the production of flowering in tulips, hyacinths, and crocuses by prolonging the period of illumination with electric light.

These tests showed that bulbous stocks in general did not respond to additional light, but there were a few exceptions. *Iris tingitana* var. Wedgewood and *Narcissus poeticus ornatus* responded favorably to additional light.

Annuals sown in late summer and benched in early fall produced salable flowers during January; whereas the controls did not flower. Sunshine aster, Lilac Lavender stocks, *Leptosyne maritima,* and *Centaurea suaveolens* were especially satisfactory.

Two types of buds are produced in Chrysanthemum—the crown and the terminal. The "crown buds" are flower buds which appear first and are distinguished by being surrounded by leaf buds. A second crown may also appear later. The "terminal" is also a flower bud and is always surrounded by other flower buds. In shaded chrysanthemums only terminal buds appear.

Explanations for early flowering of short-day plants like the chrysanthemum when the days are reduced are not obvious. Many theories have been advanced, but, as yet, not enough experimental data have been produced to establish any one of them.

COMMERCIAL VALUE

The commercial value of decreasing the daylight period of the chrysanthemum is of importance. The earliness of flowering secured by this means enables the greenhouse grower to compete with the production of outdoor chrysanthemums grown on the Western Coast. Under normal summer daylight in the greenhouse only the early, small flowered types mature in September and are placed in competition with the large mid-season varieties which mature at that time under the climatic conditions and treatment they receive on the Pacific coast. Shading enables the greenhouse producer to mature these same varieties so as to place them in competition with the western-grown material. Because of closeness to market and greater freshness, these command satisfactory returns.

Ordinarily, to secure a succession of bloom through the season, the greenhouse producer is compelled to rely upon many varieties which mature at different periods. Frequently, these varieties possess inferior qualities. Through the use of shade and its application at different stages in the growth of the plant, one good variety may be prolonged in its blossoming period and thus eliminate the use of inferior types; for example, an outstanding yellow variety, Mrs. H. E. Kidder, flowers normally from October 15 to 30. By applying the shade on July 15, it may be brought into bloom by

September 15, or, if wanted later, the shade may be applied at a correspondingly later date. The period of successive flowering may thus be prolonged from September 15 to October 30. Increased length of day by electric light may further extend this bloming period.

The growing of standard and pompon types out-of-doors is also feasible, providing that a tobacco cloth house is erected to protect the plants from the elements after the shading with black cloth is completed.

The use of supplementary electric light to increase the daylight period is also commercially feasible because of the low costs involved in the use of electric light of low intensity. The installation of an expensive lighting system is not necessary provided that care is exercised in not overloading the lines, with subsequent drop in voltage and danger of burning wires. Where the cost of electricity does not exceed 3 cents per kilowatt hour, many crops may be grown profitably, from the standpoint of earliness of production and consequent higher prices.

Supplementary electric light may be used upon long-day crops which are lagging behind in their growth, provided other cultural practices are adequate.

SPECIFIC RECOMMENDATIONS

Additional Light

1. Use 100-watt lamps.
2. Space 4 feet apart, 18 inches above plants (each lamp to cover space 16 square feet).
3. Turn light on at planting and continue until maturity.
4. Use "long-day" crops only.

Reduced Light

Chrysanthemum

1. Plant not later than June 1.
2. Use black shades covering sides and tops.
3. Shade from 5 P. M. until 7 A. M.
4. Begin shading 6 weeks after planting.
5. Remove shade on standard varieties about one week after terminal buds show.
6. Remove shade on pompons after buds show color.

Stevia

1. Use black shades.
2. Begin shading in September.
3. Shade from 3 P. M. until 7 A. M. for 4 weeks.

SUMMARY

1. Four hours of increased daily illumination from 6 P. M. to 10 P. M. from 50 to 100-watt clear glass, nitrogen filled, tungsten filament, Mazda lamps produced earliness of bloom in such potted plants as *Calceolaria hybrida, Cineraria multiflora,* and *Primula obconica.*

2. *Cyclamen persicum, Pelargonium zonale* (Geranium), *Asparagus sprengeri,* and *Asparagus plumosus* showed increased size under the increased daylight period.

3. Bulbous plants showed little or no response to this increased illumination, with the exception of *Lilium longiflorum* and *Iris tingitana.* In the case of lilies, earliness was secured; whereas Iris responded by increasing the percentage of flowering.

4. The following annuals showed striking differences in earliness of bloom when subjected to 4 hours of increased daylight: *Antirrhinum majus* (Snapdragon), *Centaurea cyanus, Centaurea imperialis, Chrysanthemum coronarium, Chrysanthemum segetum, Coreopsis tinctoria, Cynoglossum amabile, Delphinium ajacis, Didiscus caerulea, Iberis umbellata, Gaillardia lorenziana, Gypsophila elegans, Leptosyne maritima, Matricaria capensis* (Feverfew), *Mathiola incana* (Stocks), *Salpiglossis sinuata, Scabiosa atropurpurea, Schizanthus pinnatus.*

5. In the same manner a number of early flowering herbaceous perennials responded to the treatment. They were: *Achillea millifolium, Chrysanthemum maximum* (Shasta Daisy), *Coreopsis lanceolata, Gaillardia grandiflora, Viola tricolor.*

6. The Boston Yellow Daisy, under the same treatment, produced earlier, larger flowers on longer stems and in greater profusion.

7. *Centaurea cyanus* produced the greatest number of flowers at an early date when subjected to 60-day treatment with 100-watt lamps, for an additional 4-hour period.

8. Additional illumination of low intensity during cloudy weather failed to bring about results commensurate with the cost involved.

9. Low-intensity supplementary illumination had a marked effect on the flowering of long-day plants. In some instances the growth was slightly weaker than that produced under normal light conditions; however, the flowers produced were marketable.

10. Temperature variations were very small under the lighted plots as compared with the control plots.

11. By reducing the daylight period from 6 P. M. to 7 A. M. on chrysanthemums, a difference of 25 to 56 days was obtained in advance of the check. Shading caused the formation of the terminal buds instead of the crown buds formed under normal conditions.

12. Chrysanthemums produced under reduced daylight period were equal to normally produced flowers. The stem length was somewhat shorter. The bronze and pink shades faded when produced early; this was due to the intense heat.

13. Complete black sateen cloth shading gave the most satisfactory results. This cloth may be used for several years.

14. White sateen shades applied overhead and completely, as well as the black sateen overhead shading, did not prove satisfactory.

15. Applying the shade too soon after planting produced short stems. Removing the shade immediately after the buds appeared produced uneven flowering in pompon varieties.

16. The duration of the light, rather than the intensity, governs the reaction of the chrysanthemums.

17. Microchemical tests of heavy nitrogen fertilized plots with reduced daylight showed large amounts of nitrates present and traces of starch and reducing sugars. Heavy fertilization with ammonium sulfate did not retard flower formation.

18. Reducing the normal daylight induced earliness in Poinsettias and Stevia.

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