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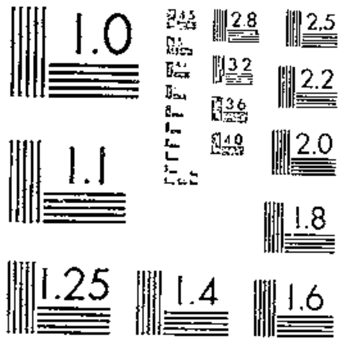
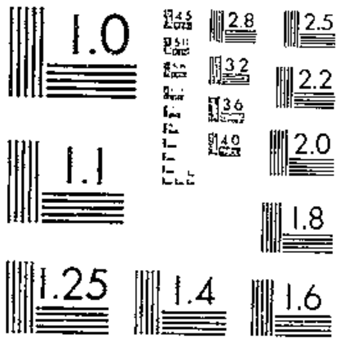


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A



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RESPONSES OF STRAWBERRY VARIETIES AND SPECIES TO DURATION OF THE DAILY LIGHT PERIOD[1]

By George M. Darrow, *senior pomologist*, and George F. Waldo, *assistant pomologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

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INTRODUCTION

Results of surveys of the varieties of strawberries grown in the United States have been published as a bulletin of the United States Department of Agriculture (*1*).[2] In this bulletin are maps showing definite regions where different varieties succeed. The Missionary is the only variety grown in Florida; until recently Klondike and Missionary have been the only two commercial sorts grown in most of the Southern States from Virginia west to southern California; Marshall, Ettersburg 121, and Clark are the three principal sorts raised in the Pacific Northwest; Aroma is raised in the central Mississippi Valley; Howard 17 (Premier) throughout the area immediately to the north and in the Northeast, and Dunlap in the most northern regions. Nearly all European varieties tested thus far grow feebly at the United States Plant Introduction Garden, Glenn Dale, Md., near Washington, showing none of the valuable characteristics that make them worth growing in different regions of Europe. Why the varieties succeeded in such definite areas was not evident, yet an understanding of the reasons is important to an evaluation of new varieties and in breeding such for any particular region.

[1] Acknowledgment is due to Hugh Sherwood, who assisted in making many of the measurements for 1931 and 1932; E. H. Haack, of the Central California Berry Growers Association, who has kindly furnished data on berry shipments from which the graphs in figure 12 were made; H. A. Allard, of the Division of Tobacco and Plant Nutrition, who has given helpful advice and extended the use of his day-length facilities; and Guy E. Yerkes, Division of Fruit and Vegetable Crops and Diseases, who made many helpful suggestions.

[2] Italic numbers in parentheses refer to Literature Cited, p. 31.

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Studies of the species of strawberries from which cultivated sorts are derived also showed regional adaptations. *Fragaria virginiana* Duch. has a wide adaptation, being native to eastern North America from Hudson Bay to northern Georgia. *F. chiloensis* Duch., however, has a restricted adaptation, being native to the beaches of the Pacific coast from Alaska to central California and southern Chile. It is also found on mountain tops in the Hawaiian Islands. A selection of this is grown at high elevations (nearly 10,000 feet) in Ecuador near the Equator, while hybrids of *F. chiloensis* with cultivated varieties are raised in Alaska. *F. chiloensis* planted in Maryland soon dies out. The selection of this species grown near the Equator in Ecuador, where the temperature is rarely higher than 65° or 70° F. and seldom lower than 35°, fruits continuously throughout the year, but in Peru it fruits through November, December, and January, and in Chile in December and January. In Maryland it has a fruiting season of about 2 weeks in June.

The daily light periods of regions where strawberries are grown range from continuous daylight for 6 weeks in summer in central Alaska to 16 or 17 hours of daylight in June in the Northern States, to 12 hours at the Equator, and 10½ to 11 hours in Florida in winter.

The experiments reported herein were conducted both in the field and in the greenhouse and were planned to give an understanding of the responses made by different species and varieties of strawberry to light conditions in the various berry regions of the United States. It is recognized that temperature factors are probably equally important in their effects on the strawberry. It was not possible to give plants daily light exposures in intensity and quality in the greenhouse which duplicate field conditions. However, in some respects the experiments have shown that greenhouse tests can be made which may be even more informing concerning the responses of different varieties than field tests would be.

Other experiments, carried on at the same time as were those reported herein, have shown that the optimum temperature for strawberry leaf growth was between 68° and 79° F., averaging about 73° (*5*). The production of runners by different varieties was found to be characteristic, the Howard 17 producing none in Maryland from axillary buds of leaves appearing after August 19 (*4*). The starting of fruit-bud formation was found to occur in Howard 17 and some other varieties in Maryland (*12*), and in the Marshall in the Pacific Northwest (*6*) by September 1, and in Ettersburg 121 on October 15 in Maryland and early in November in the Northwest. Fruit-bud development does not begin in spring-bearing varieties until the daily light period becomes relatively short in the fall (*8*). From North Carolina southward the days are sufficiently short in spring when growth starts so that fruit-bud formation in some varieties can continue into May and June, after which it is stopped by hot weather (*8*) The fall and early winter-formed fruit buds of the leading varieties in the South develop into basal-branching clusters and the later-formed fruit buds into high-branching clusters, each variety having characteristic cluster types (*2, rev.ed.; 3, 8*). In the districts of California just south of San Francisco where the summers are cool and day length approximates that of the Carolinas, fruit-bud formation may continue throughout the summer in varieties that produce a single crop elsewhere (*16*). Each variety has a characteristic response to length of daily light period and to temperature; moderate temperatures and light and dark periods of about equal length being most favorable for growth and fruit-bud production in some varieties, but shorter light periods more favorable to other sorts (*7*, *9*). Drought may stop fruit-bud formation in certain varieties (*15*), though under some conditions it is known to initiate limited fruit-bud formation, and the drying up of strawberry beds (*2*) is even used to a slight extent by growers for this purpose. Short daily light periods in fall are a cause of the rest period in strawberries (*10*).

SHORTENING THE DAILY LIGHT PERIOD IN SUMMER

EARLY EXPERIMENTS, 1923-27

In midwinter of 1923 boxes and flowerpots were placed over strawberry plants in the field in such a manner as to exclude light but allow ventilation. On May 8, when normal plants were in full bloom, those in the dark had also come to the flowering state. Although the type of growth produced was typical of etiolated plants, the test showed that light was not essential to growth after the rest period was broken by exposure to low temperatures. The leaf petioles were greatly elongated, being several times the length of those in the open; the leaflets were very small; the flowers were few, the sepals poorly developed, the petals almost wanting, and the stamens entirely lacking. The pistils were better developed than other floral parts, but they were very small. In the absence of light, stored food materials apparently were sufficient for little, if any, cell division, but conditions were satisfactory for cell enlargement.

Throughout the summers of 1923, 1924, and 1925, boxes (12 by 18 inches by 6 feet), painted white on the outside with ventilators adjusted to exclude light, were placed over plants of Missionary, Dunlap, Howard 17, Klondike, Progressive (an everbearing sort), and Portia in the field about 4:30 p.m. and left until 7:30 a.m., giving an 8½- to 9-hour period of daylight. Under these shortened periods of light exposure, vegetative growth was reduced and a small number of fruit buds formed each year on the Missionary and more rarely on some other sorts.

In 1926, Howard 17, Missionary, and Dunlap were grown in flats and placed under 8-, 10-, and 12-hour daylight periods from July 16 to September 4. No evidence of fruit-bud formation due to the shorter daylight periods for this limited time was found.

In 1927, the Howard 17, Missionary, Dunlap, and Progressive were placed under 10- and 12-hour and normal daily light periods from May until the end of October. Under the 10-hour period the Howard 17, Missionary, and Dunlap blossomed by the end of July, while Progressive, the everbearing sort, produced no blossoms. Under the 12-hour and normal light periods no flowers were produced except by Progressive, which blossomed freely throughout the summer. Under the 10-hour day, Howard 17 produced no flowers after July 28, while Missionary and Dunlap did. Under the 12-hour day by October 26 Howard 17, Missionary, and Dunlap had all produced some flower clusters. These tests indicate that except for everbearing sorts the varieties worked with will form fruit buds only to a limited degree, if at all, under short daylight periods at high summer temperatures.

Apparently both length of light exposure and temperature are factors in inducing fruit-bud initiation in these varieties.

Tests for these first 5 years showed that the everbearing varieties tested form fruit buds and grow freely under the long days of midsummer but do not differentiate fruit buds in daily light periods at summer temperatures of much less than 12 hours. In contrast the spring-fruiting varieties form fruit buds in the normal short days of fall and likewise (though sparingly) under artificially shortened days at high temperatures in midsummer.

EXPERIMENTS IN 1928 AND 1929

In the summers of 1928 and 1929 five plants each of Progressive, Rockhill, Pearl, Howard 17, Missionary, Dunlap, Fairfax, a variety from Mexico, and one from Alaska were grown in pails with the Allard equipment under 10-hour, 12-hour, and normal daylight periods from April to October, and detailed records were taken on their runner, leaf, flower cluster, and flower production. The averages per plant for all varieties, and detailed records for Missionary, a southern sort, Howard 17, a northern sort, and Progressive, an everbearing sort, are given in table 1. For the Mexican variety the number of flower clusters in the spring of 1929 was 9.3, 17.0, and 2.2 for the 10-hour, 12-hour, and normal daylight exposures, respectively.

TABLE 1.—*Strawberry growth records per plant for the summers of 1928 and 1929 under three daily light periods, and flower production per plant in the spring of 1930 on the same plants*

Variety and light period	Runners		Leaves		Leaf area, 1928			Flower clusters, 1929	Flowers, spring, 1930
	1928	1929	Oct. 6, 1928	Oct. 23, 1929	July 18	Aug. 17	Oct. 8		
	Number	*Number*	*Number*	*Number*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Number*	*Number*
Missionary:									
10-hour	4.0	15.4	21.6	52.7	43	20	81	1.4	70.8
12-hour	18.6	30.0	20.2	45.4	98	71	140	.8	53.6
Normal	10.4	36.4	9.2	24.0	105	166	132	.0	24.2
Howard 17:									
10-hour	.4	.6	35.0	67.6	39	55	95	.0	37.0
12-hour	1.8	6.8	50.2	75.8	89	100	134	.0	21.6
Normal	16.6	29.8	14.6	41.5	119	138	148	.0	21.2
Progressive:									
10-hour	.8	3.8	16.8	30.4	38	48	73	6.4	58.2
12-hour	6.0	12.2	25.8	73.0	81	82	182	4.2	62.0
Normal	2.6	10.4	25.8	72.4	110	122	111	40.0	44.2
Average, 9 varieties:									
10-hour	1.8	6.7	23.5	50.0	[1] 37	[1] 41	[1] 76	--------	[2] 45.2
12-hour	7.8	16.1	25.0	58.6	[1] 74	[1] 89	[1] 149	--------	[2] 42.0
Normal	13.7	27.0	15.8	38.3	[1] 140	[1] 150	[1] 120	--------	[2] 22.2

[1] Average of 8 varieties. [2] Average of 7 varieties.

Table 1 shows several characteristic differences between typically southern, northern, and everbearing varieties at the usual summer temperatures of Washington, D.C. In runner production, in leaf number, in leaf area, in flower clusters, and in number of flowers, these three varieties show the characteristic differences of southern varieties (Missionary) adapted to short days, of northern varieties (Howard 17) adapted to long days, and of everbearing varieties (Progressive) adapted to long days in the North. Missionary produced runners freely under 12-hour and normal but not under the 10-hour days; Howard 17 produced runners freely under normal long days but not under 10- and 12-hour days; whereas the Progressive did not produce them freely at all under 10- or 12-hour or normal days. Except in the variety from Alaska, runner production ceased by the end of June under the 10-hour day; even under the 12-hour day it ceased for the Howard 17 but not for the others. Missionary and Dunlap produced runners freely under the 12-hour day.

In 1928 in number of leaves the 12-hour day series was first, the 10-hour day second, and the normal day third; in 1929 the 10-hour and 12-hour day series were about the same and the normal-day series much less.

In leaf area per plant the normal-day series was greatest until October 8. The leaves on the 10-hour series were much the smallest, resembling leaves produced in late fall in the field. Fewer crowns were produced in the normal-day than in the 10-hour and 12-hour series.

The Progressive overbearing variety produced 40-flower clusters per plant during the summer on the normal-day plants and but 4.2 and 6.4 on the 12-hour and 10-hour day plants, respectively. It is especially noteworthy that the variety from Mexico, which comes from a region with days and nights nearly equal, produced the most flower clusters on the 12-hour day plants.

In the spring of 1930 plants of Missionary kept under 10- and 12-hour daylight periods the previous year produced over twice as many flowers as those in the normal-day series. Apparently a longer growing period in the fall when the days are short enough for fruit-bud formation resulted in many more flowers in the spring. The Alaskan and Mexican varieties, as well as the Progressive, however, produced more flowers in the 12-hour than in the 10-hour or normal-day series.

The experiments for these two summers indicated a general trend of response by the strawberry but also a characteristic response by varieties to daily light periods in all the phases of plant growth that were measured. They showed clearly that a long summer day at elevations near sea level is necessary for fruit production in the everbearing sorts tested. When the day length is shortened, growth is slowed up and the plants are dwarfed. The indications are that present varieties of everbearing strawberries are adapted only to the northern parts of the United States where the summer days are long. Observations confirm these results. The common everbearing varieties in the field in the Southern States as a rule produce no runners and are dwarfed as they were in these experiments. Breeding results also confirm this. Seedlings resulting from crosses between the Rockhill, an everbearing sort, and the Missionary have been grown at Willard, N.C. Some grew freely under the relatively shorter days there in summer, while others did not, and responded as did the Rockhill and Progressive in these experiments.

The response of the Howard 17 corresponds to its response in the field in different regions. In Ohio and New Hampshire it makes runners to the end of the growing season, but in Maryland initiation of runners usually ceases in the latter part of August and very few appear after the first week in September. Farther south at Willard, N.C., few runners are produced at any time, and the plants finally die out. In contrast, the Missionary variety produced runners freely even under the relatively short summer days in Florida and still more freely in North Carolina and Maryland. Southern varieties like the

Missionary make such a rank growth of runners and leaves that they are not adapted to the Northern States.

LENGTHENING THE DAILY LIGHT PERIOD IN WINTER

EXPERIMENTS IN 1928-29 AND 1929-30 IN THE GREENHOUSE

Four plants each of many varieties and species (132 in 1928 and 81 in 1929) were potted during August and September (in some cases later) and held in coldframes. In 1928 the first series having no rest period was brought into the greenhouse October 15; the second series after a short rest period was brought in December 10; the third after a longer rest period was brought in on January 24. In 1929, the first series was brought in October 21, and the lights were turned on November 7; the second series was brought in December 6 after a

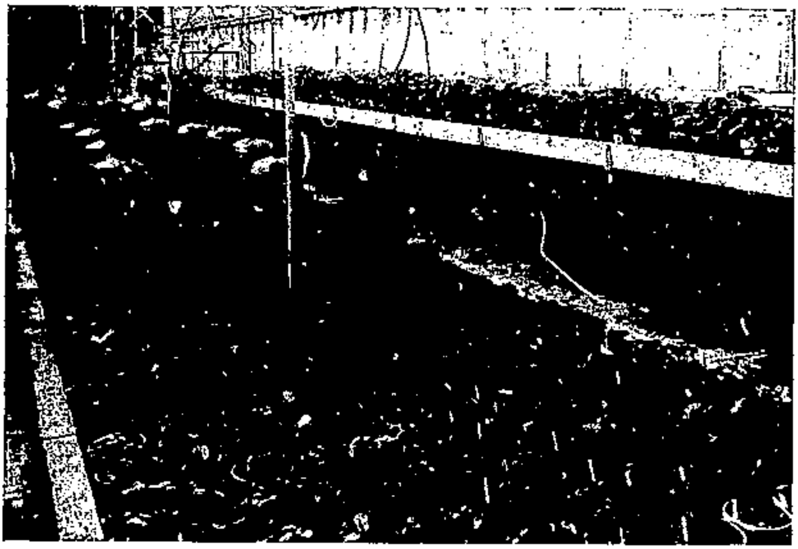

FIGURE 1.—Arrangement of plants and of electric lights in the greenhouse in 1929-30. In the center bed are plants in series 1 in the experiment running from November 7, 1929, to March 10, 1930. On the side benches are the plants in series 2 in the experiment running from December 18, 1929, to March 10, 1930. In the foreground are the normal-day lots.

short rest period and the lights were turned on December 18. The plants for the three 1928–29 series were grown under three conditions, (1) daylight only, (2) 100-watt, and (3) 200-watt electric lights from dark to 10 p.m. to supplement daylight. In 1929–30 the three conditions for the two series were (1) daylight only, (2) 200-watt, and (3) 1,000-watt lights for half of each night to supplement daylight. For 1929–30 there were nine 200-watt lights at a height of about 2.3 feet above the pots to cover 75 square feet of bench and five 1,000-watt lights about 3 feet above the plants to cover an equal space (fig. 1). The temperatures averaged about 70° F. during the day both winters, and 60° to 70° at night in 1928–29 and 50° to 60° in 1929–30. While the 200-watt and 1,000-watt lights were on, the air temperatures around the plants were 4° to 5° and 20° to 25° higher, respectively, than where there were no lights.

The responses under the 100-watt lights were similar to but less pronounced than those under the 200-watt lights; those under 1,000-watt lights were similar to those under the 200-watt lights. The relatively great increase in temperature under the 1,000-watt lights caused somewhat different responses in some varieties but did not obscure the general trend. The results for the 2 years were similar, although minor differences, apparently due to the variation in night temperatures and perhaps to the difference in conditions before the plants were brought into the greenhouse, were apparent. The response of the varieties and species is therefore represented by the figures for 1929–30 experiments in tables 2 and 3 for the more important or for representative varieties.

TABLE 2.—*Relative area in terms of total leaf product of all mid leaflets and the length of the tallest petiole on one plant, and the average number of flower clusters on the four plants in each lot (normal day, normal day plus 200-watt lights, and normal day plus 1,000-watt lights) of each series for 15 varieties and species on Mar. 11, 1930*

[Electric light exposures half of each night; greenhouse experiments in Washington, D.C.]

Variety and light exposure	Series 1 (Nov. 7, 1929–Mar. 11, 1930)			Series 2 (Dec. 18, 1929–Mar. 11, 1930)		
	Leaf product	Flower clusters	Tallest petiole	Leaf product	Flower clusters	Tallest petiole
	Cm²	*Number*	*Cm*	*Cm²*	*Number*	*Cm*
Missionary:						
Normal	278	2.5	15	101	1.3	12
200-watt	200	2.8	13	300	1.8	18
1,000-watt	217	----------	16	420	1.0	26
Blakemore:						
Normal	163	3.8	7	135	2.0	5
200-watt	260	3.3	12	275	1.8	22
1,000-watt	300	3.7	10	331	1.8	26
Klondike:						
Normal	283	2.3	12	254	1.3	8
200-watt	384	1.7	18	263	1.8	21
1,000-watt	335	1.3	18	580	2.0	22
Aroma:						
Normal	60	1.5	7	43	.7	7
200-watt	117	1.3	11	170	1.0	13
1,000-watt	242	2.0	11	187	1.0	12
Chesapeake:						
Normal	166	1.8	13	108	1.0	7
200-watt	342	2.5	14	270	1.0	17
1,000-watt	173	1.8	8	315	1.0	18
Ettersburg 121:						
Normal	466	7.0	----------	242	3.5	----------
200-watt	525	3.5	----------	573	3.5	----------
1,000-watt	601	5.0	----------	460	5.3	----------
Mastodon:						
Normal	46	2.5	3	43	----------	2
200-watt	335	4.0	9	124	2.0	8
1,000-watt	279	5.2	9	145	2.0	11
Howard 17:						
Normal	75	1.5	5	63	----------	5
200-watt	168	3.5	11	160	2.7	11
1,000-watt	59	2.8	8	337	2.0	22
Bellmar:						
Normal	100	----------	4	158	----------	0
200-watt	193	----------	13	379	1.3	21
1,000-watt	317	----------	13	176	.5	22
Marshall:						
Normal	103	2.8	5	115	1.3	6
200-watt	95	1.8	7	107	2.0	11
1,000-watt	110	2.0	6	331	1.3	15
Excelsior:						
Normal	161	2.5	8	----------	----------	----------
200-watt	183	4.3	12	----------	----------	----------
1,000-watt	97	2.3	13	----------	----------	----------
Southland:						
Normal	200	1.8	----------	292	----------	----------
200-watt	417	1.5	----------	361	----------	----------
1,000-watt	437	----------	----------	337	----------	----------

TABLE 2.—*Relative area in terms of total leaf product of all mid leaflets and the length of the tallest petiole on one plant, and the average number of flower clusters on the four plants in each lot (normal day, normal day plus 200-watt lights, and normal day plus 1,000-watt lights) of each series for 15 varieties and species on Mar. 11, 1930*—Continued

Variety and light exposure	Series 1 (Nov. 7, 1929–Mar. 11, 1930)			Series 2 (Dec. 18, 1929–Mar. 11, 1930)		
	Leaf product	Flower clusters	Tallest petiole	Leaf product	Flower clusters	Tallest petiole
	Cm²	*Number*	*Cm*	*Cm²*	*Number*	*Cm*
Pearl:						
Normal	17	.5	2	95	.5	4
200-watt	110	1.8	10	224	1.3	14
1,000-watt	172	2.0	11	138	.8	13
Dunlap:						
Normal	38	2.0	4	42	.0	3
200-watt	32	4.3	5	130	3.0	12
1,000-watt				130	3.0	12
Fragaria sp. (Harlan):						
Normal	79	.0	7	179	.0	11
1,000-watt	443	7.0	18	416	2.0	23

TABLE 3.—*Flower production of 12 strawberry varieties and total of 57 varieties in the greenhouse under normal day length and with additional 200- and 1,000-watt lights*

[4 plants in each lot]

Variety and light exposure	Series 1 (Nov. 7, 1929–Mar. 10, 1930)										Series 2 (Dec. 18, 1929–Mar. 8, 1930)						
	Nov. 29	Dec. 7	Dec. 20	Dec. 30	Jan. 7	Jan. 20	Jan. 27	Feb. 3	Feb. 21	Mar. 10	Jan. 13	Jan. 20	Jan. 27	Feb. 3	Feb. 8	Feb. 20	Mar. 8
Missionary:																	
Normal	0	0	0	3	5	24	20	20	44	75	0	0	1	2	6	21	41
200-watt	0	0	7	16	42	54	73				0	1	4	13	30	53	64
1,000-watt	0	0	10	26	40	64	76				0	4	11	25	33	45	45
Heflin:																	
Normal	0	0	0	0	4	7	15	10	29	67	0	0	0	1	3	18	29
200-watt	0	0	1	11	20	50	54				0	0	0	7	14	28	37
1,000-watt	0	2	22	40	68	75	84				0	0	3	16	22	33	47
Blakemore:																	
Normal	0	0	0	0	1	11	19	25	30	62	0	0	0	0	0	5	23
200-watt	0	0	3	12	33	38	44				0	0	0	0	1	18	37
1,000-watt	0	4	30	32	40	51	68				0	2	4	0	14	24	44
Klondike:																	
Normal	0	0	0	0	0	0	1	1	15	57	0	0	0	0	0	3	10
200-watt	0	0	0	2	6	12	24				0	0	0	2	13	36	52
1,000-watt	0	0	8	20	43	44	52				0	0	2	12	27	47	58
Aroma:																	
Normal	0	0	0	0	0	0	0	1	7	7	0	0	0	0	0	0	0
200-watt	0	0	0	0	0	7	13				0	0	0	0	5	19	25
1,000-watt	0	0	0	0	0	18	21				0	0	0	0	3	11	17
Chesapeake:																	
Normal	0	0	0	0	0	0	0	0	4	24	0	0	0	0	0	0	1
200-watt	0	0	0	0	0	10	22				0	0	0	0	0	0	20
1,000-watt	0	0	1	8	19	34	38				0	0	0	0	0	7	34
Ettersburg 121:																	
Normal	0	0	0	0	0	0	0	0	13	80	0	0	0	0	0	7	41
200-watt	0	0	0	0	5	26	38				0	0	0	0	0	10	77
1,000-watt	0	0	0	3	15	27	57				0	0	0	0	0	6	86
Mastodon:																	
Normal	0	0	0	0	0	0	2	4	5	10	0	0	2	2	2	2	2
200-watt	0	0	0	0	0	9	15				0	0	0	0	0	2	5
1,000-watt	0	0	3	6	24	25	25				0	0	0	4	4	11	11
Howard 17:																	
Normal	0	0	0	0	0	0	0	0	2	10	0	0	0	0	0	0	0
200-watt	0	1	7	12	28	41	42				0	0	0	0	1	11	23
1,000-watt	2	14	22	26	33	45	48				0	0	0	1	7	21	37
Bellmar:																	
Normal	0	0	0	0	0	2	8	12	23	40	0	0	0	0	1	7	16
200-watt	0	0	5	10	34	44	46				0	0	0	1	4	28	57
1,000-watt	0	0	8	14	16	30	34				0	0	0	1	1	4	6
Marshall:																	
Normal	0	0	0	0	0	5	9	13	19	19	0	0	0	0	0	6	13
200-watt	0	0	2	7	21	33	33				0	0	0	0	5	14	28
1,000-watt	0	0	14	25	37	41	41				0	0	0	1	3	5	10

TABLE 3.—*Flower production of 12 strawberry varieties and total of 57 varieties in the greenhouse under normal day length and with additional 200- and 1,000-watt lights*—Continued

Variety and light exposure	Series 1 (Nov. 7, 1929-Mar. 10, 1930)										Series 2 (Dec. 18, 1929-Mar. 8, 1930)						
	Nov. 20	Dec.			Jan.			Feb.		Mar. 10	Jan.			Feb.			Mar. 8
		7	20	30	7	20	27	3	21		13	20	27	3	8	20	
F. virginiana (27):																	
Normal	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	3
200-watt	0	0	0	2	16	42	57	----	----	------	0	0	0	0	0	4	40
1,000-watt	0	0	13	42	74	98	136	----	----	------	0	0	0	0	0	5	64
Total, 57 varieties:																	
Normal	----	0	0	9	55	115	220	330	748	1,524	0	3	7	15	33	190	647
200-watt	----	5	71	178	588	1,251	1,612	----	----	------	0	4	17	60	137	507	1,490
1,000-watt	3	40	374	851	1,511	2,241	2,622	----	----	------	14	32	76	204	310	876	1,594

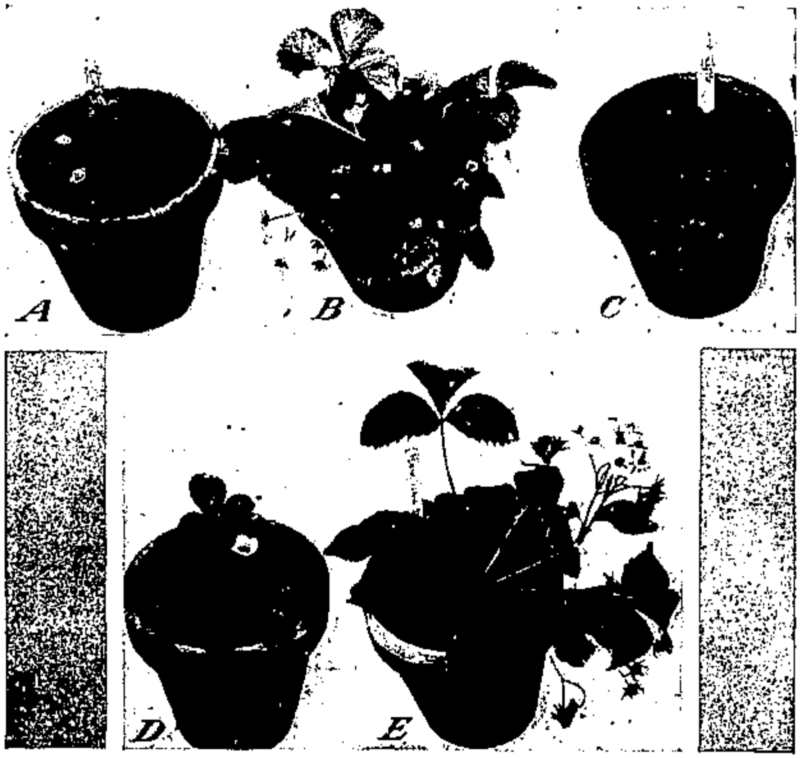

FIGURE 2.—Responses of strawberry varieties to the normal light of winter in the greenhouse at Washington, D.C. Almost no growth was made by Mastodon (*A*) and Dunlap (*C*) and very little by Howard 17 (*D*), while Southland (*B*) and Missionary (*E*) made a vigorous growth.

From the very beginning of these winter experiments it was evident that the response of varieties was characteristic and far more informing than the summer experiments. Varieties could be classified as follows: (1) Those that grew vigorously from October 15 under normal light, such as Missionary (fig. 2, *E*), Klondike, Blakemore, Ettersburg 121, Excelsior, and Southland (fig. 2, *B*); (2) those that grew well only when given additional light, such as Chesapeake, Bellmar (fig. 3), Narcissa, and Marshall; (3) those that grew well only after a low-temperature rest period, such as Howard 17 (figs. 2, *D* and 5, *D*), Fairfax (fig. 4), Dunlap (fig. 5, *A*), and Campbell; (4) the everbearing sorts that did not grow well in the greenhouse

FIGURE 3.—The Bellmar strawberry grown in the greenhouse in winter at Washington, D.C.: *A*, and *B*, Normal daylight only (*A*, Oct. 15 to Apr. 1, *B*, Jan. 24 to Apr. 1), *C* and *D*, normal daylight plus 200-watt lights for about 5 hours each night (*C*, Oct. 15 to Apr. 1, *D*, Jan. 24 to Apr. 1). Plants of this variety show some response to a rest period (*B*) but more response to additional daily light (*C*), while the exposure to additional light after a rest period (*D*) resulted in a vigorous growth.

under the conditions given, as represented by Mastodon (fig. 2, *A*). The striking differences obtained may be suggested by the average number of flower stems (table 2, series 1) produced under normal light in the November 7 series by Ettersburg 121 7.0 clusters, by Chesapeake 1.8 clusters, by Howard 17 1.5 clusters, and by Mastodon

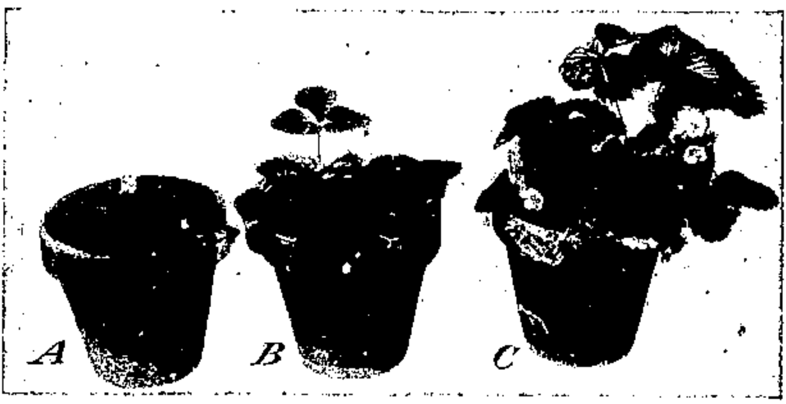

FIGURE 4.—Plants *A* and *B* were brought into the greenhouse December 10 at Washington, D.C., *A*, receiving normal daylight only, *B* receiving electric light for half the night in addition to daylight. Plant *C* was brought into the greenhouse January 24 and received normal daylight only. This variety, Fairfax, shows some slight response to additional daily light (*B*), but a far greater response to a rest period (*C*). Photographed April 1, 1920.

2.5 clusters. That is, the Ettersburg 121 plants continued to grow and produce fruit buds all winter under the short days and low light intensity of the greenhouse, while the fruit buds already formed November 7 in the other varieties developed but no others formed. Ettersburg 121 produced fruit buds under such conditions even more freely than Missionary and others of its group. The average leaf area of Ettersburg 121 plants in this series was nearly 30 times that of the Pearl (two plants died), over 10 times that of Mastodon, 6 times that of Howard 17, and over 4 times that of Bellmar.

Within the groups different varieties showed notable differences, each sort having apparently characteristic responses to light intensity or temperature or a combination of both. Thus in the November 7 series the leaf area of Missionary plants when given added light was

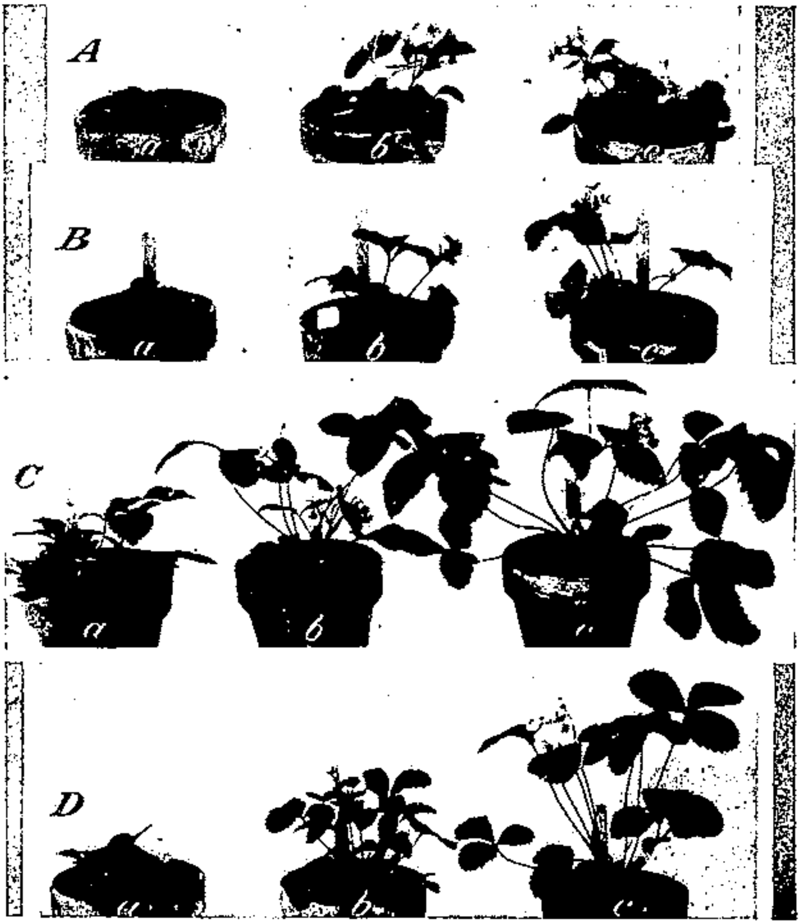

FIGURE 5.—Responses of Dunlap (*A*), Mastodon (*B*), Klondike (*C*), and Howard 17 (*D*) to artificial light to supplement normal daylight at Washington, D.C., from December 18, 1929: to March 10, 1930 *a*, Normal-day plants; *b*, plants receiving normal daylight plus 200-watt lights to 10 p.m.; *c*, plants receiving normal daylight plus 1,000-watt lights to 10 p.m.

not as great as for the normal-day plants, while for the Blakemore the leaf area was greater the more intense the light given. After a brief low temperature rest period, however, the Missionary as well as the Blakemore made a very vigorous vegetative growth which was greater the more intense the light given.

The petiole length was also found to be affected in a characteristic manner by the length of the daily light period, and the length of the tallest petiole on each plant was taken as a measure of this response of the variety to light conditions. The last column in table 2, giving the petiole lengths in series 2 and the plants in figures 5 to 8, show the much greater length of the petioles under additional daily light. After a long period in the greenhouse as represented by the figures for tallest petiole in series 2 the petiole lengths of some of the normal-day plants may become nearly as long as those on the 200-watt or 1,000-watt plants.

Development equal to that of out of doors in summer did not take place in the normal-day plants during November, December, and January. Development approaching that of out of doors in character but at a much slower rate took place in Bedarena, Blakemore, Ettersburg 121, Excelsior, Klondike (fig. 5, *C*), Missionary (fig. 2, *E*), Southland (fig. 2, *B*), *Fragaria vesca semperflorens* Duch. (fig. 6, *A*), *F. chiloensis* Duch. (fig. 6, *B*), and *F. moschata* Duch. Noticeable growth occurred in Bellmar (fig. 4), Deutsch Evern, Fendalcino, Heflin, Judith, and Marshall. Slight growth occurred in *F. vesca alba*, *F. virginiana* (27) Duch. (fig. 6, *C*), Howard 17 (fig. 2, *D*, and 5, *D*), Sybil, Narcissa, and U.S.D.A. 682. Practically no growth occurred in Aroma, Chesapeake, Clermont, E. Versin, Gene, Mme. Moutot, Portia, and a variety from the Azores, while Annas de Guemene, Colvert, Dr. Hogg, Dunlap (fig. 5, *A*), *Fragaria* sp.[3], *Fragaria* sp.[4], Mastodon, and Pearl actually became weaker.

Fewer flowers with pollen-filled anthers were produced under lights than under field conditions. Anthers lacking pollen, together with green and partially developed petals, were also characteristic of flowers, produced in the greenhouse by plants without artificial illumination and may be assumed to be due to malnutrition associated with too short light periods or too low light intensity. Such flowers have been seen in the field in winter at Willard, N.C. The mature fruit of most varieties (when ripened in the greenhouse) was intensely acid and not of high flavor. This was especially noticeable with Howard 17, Blakemore, Missionary, and Excelsior. In contrast, Fairfax and U. S. D. A. nos. 1015 and 682 had very high flavor, whereas Marshall and Deutsch Evern had good flavor under the same conditions. These results correspond to those of the New York (Geneva) State Agricultural Experiment Station (*14*), with shading experiments out of doors, and indicate a need for greater light intensity under glass for the production of high-flavored fruits of many sorts.

The total flower production of 57 varieties of strawberries (table 3) in series 1 up to January 27 after nearly 3 months' exposure to normal day, 200-watt and 1,000-watt lights, was 226, 1,612, and 2,622 flowers, respectively, and after approximately the same length of time for the December 18 series (series 2) it was 647, 1,480, and 1,584 flowers for the normal day, 200-watt and 1,000-watt lights. In general, flower production in series 1 was fastest in the 1,000-watt lot, about 2 weeks slower in the 200-watt lots, and 9 weeks slower in the normal-day lot. In series 2, however, there was little difference between the 1,000-watt and the 200-watt lots, whereas the normal-day lot was about 2 weeks behind. However, as indicated by the record for Ettersburg 121 in series 1, far more fruit buds and flowers are produced by some varieties under the normal daylight of winter than under the longer periods obtained by the use of electric lights.

[3] A wild strawberry native to Manchuria, collected by Dorsett.
[4] A wild strawberry native to Kashmir, collected by Harlan.

FIGURE 6.—*A*, *Fragaria vesca semperflorens* Duch. This variety, Erige du Poitou, of the European wood strawberry, grew well under the normal light of winter at Washington, D.C. (*a*); and only slightly better under the normal light plus the 200-watt and 1,000-watt lights for part of each night (*b* and *c*) from November 7 to January 6. Note the runners produced on both the 200-watt and the 1,000-watt plants. *B*, *Fragaria chiloensis*. This selection of the wild beach strawberry of the Pacific coast grew fairly well under the normal light of winter at Washington, D.C., (*a*), but started flowers if given in addition 200-watt lights (*b*), and flowers and runners under 1,000-watt lights (*c*) from November 7 to January 6, 1930. *C*, *Fragaria virginiana* (27). This selection of the wild strawberry of eastern North America was unable to grow under the normal light of winter at Washington, D.C., (*a*), but when given additional light by the use of 200-watt (*b*), or 1,000-watt (*c*) lights, November 7 to January 6, vigorous growth resulted.

Considering both series, Missionary produced flowers the quickest of any variety under normal light conditions of winter and almost as many flowers under the 200-watt light as under the 1,000-watt. Fruit-bud production continued throughout the winter just as it does in Florida. This further indicates the adaptability of this variety to short days of low light intensity, such as occur in winter in Florida. The production of runners by the Missionary under the 200-watt and 1,000-watt lights indicates that this variety quickly becomes vegetative under longer days. Of the other varieties, Heflin was the nearest like Missionary in flower production. Blakemore, Southland, and Klondike also made a response similar to Missionary, which corresponds to their adaptation to southern States where the Missionary succeeds best.

The opposite extreme in response was made by such varieties as Aroma, Chesapeake, Dunlap, and Mastodon. Under the short days and low light intensity of the normal winter day the Aroma and Chesapeake grew very little, their petals were greenish, and the flowers only partially developed. Their development under field conditions indicates their adaptation to regions (Maryland to Missouri) with relatively long days. The Dunlap used in these experiments also grew little and bore greenish petals. Waldo (*15*) has shown that it develops its fruit buds fairly early and quickly, whereas the Chesapeake and Aroma develop their fruit buds later and more slowly. The Dunlap is, therefore, adapted to regions farther north than the Chesapeake and Aroma, where onset of cold weather and of the dormant period follows soon after shortening of the daylight periods in the fall. Mastodon, an everbearing sort, under the normal day grew feebly at first and finally failed to make any growth; even under the 1,000-watt lights growth was not normal.

Although the Ettersburg 121 made an exceptionally vigorous growth under the normal day it did not produce flowers until late. Its vigorous vegetative growth and production of flowers in the greenhouse under the normal winter day indicate its adaptation to regions where conditions are favorable for growth and fruit-bud differentiation in late fall and winter. Such conditions are found in the Pacific Northwest where this variety is grown commercially. There Ettersburg 121 does not start fruit-bud formation until about November 1, which is usually after the rainy season has started and the plants are in vigorous growth. Then, as its leaves are entirely evergreen during the mild winters there, many fruit buds are differentiated and become well developed by spring. Conditions are also favorable for growth and fruit-bud differentiation in winter in Florida and other parts of the Southeast, but the temperatures in summer are too high for this sort.

The Howard 17 did not grow in the normal-day lot of series 1 and very little in the corresponding lot of series 2. Its growth in the 200-watt and 1,000-watt lots was not entirely normal but was much better in series 2 than in series 1.

The Bellmar, a cross between Missionary and Howard 17, resembles the latter more than the former in its behavior. It grew slowly with many green-petaled flowers under the normal day of winter in series 1 but much better in series 2. Even in the 200-watt lot of series 1 many petals were greenish and the fruit abnormal.

The Marshall responds more like the Bellmar, but did not develop satisfactorily in any lot. Although flowering was advanced, this variety seems to be one of the least affected by the daylight period as such. In the field it is adapted to northern regions, but it is also raised extensively in California where the days are more than 13 hours long in May and more than 14 hours in June; in fact, the highest yields known in this region are of the Marshall variety. Apparently some other condition besides light affects adaptation in that region.

These responses of the different varieties again correspond to the known adaptation of varieties in the field. Missionary is best adapted to Florida with its short winter days and Blakemore for the regions with somewhat longer days north of Florida. Ettersburg 121 succeeds best by far in western Oregon where it develops fruit buds all winter in the short days and low light intensity but does not succeed in the Southeast, apparently because of high summer temperatures. On the other hand, Missionary does not succeed in the Northwest because the prevailing winter temperatures are too low. Chesapeake needs the longer days though not necessarily the rest period of the Northern States. Howard 17 needs the longer days and a rest period, while Mastodon needs not only long days and a rest period but more intense light as well.

EXPERIMENTS IN 1930-31 AND 1931-32 IN THE GREENHOUSE

During the winters of 1930–31 and 1931–32 experiments were carried on both at Corvallis, Oreg., and at Washington, D.C., under the same general plan as in 1929–30. To a considerable extent the work was designed to discover measures for the evaluation of new sorts. Length of leaf petioles and number of new leaves, runners, and flowers produced under normal light during the winter were all found useful, and in general were similar, measures of varietal response to conditions. Tables 4 and 5 give the average petiole length and number of new leaves produced by the 1930–31 series of varieties grown in the greenhouse at Washington.

TABLE 4.—*Average length of petioles of all leaves produced from Nov. 17, 1930, to Feb. 1, 1931, and from Jan. 2 to Apr. 30, 1931, at Washington, D.C.*

Variety and species	Nov. 17, 1930–Feb. 1, 1931			Jan. 2, 1931–Apr. 30, 1931					
				Normal day		200-watt light		1,000-watt light	
	Normal day	200-watt light	1,000-watt light	October plants	January plants	October plants	January plants	October plants	January plants
	Cm	*Cm*	*Cm*	*Cm*	*Cm*	*Cm*	*Cm*	*Cm*	*Cm*
Ettersburg 121	15	29	27	22	33	31	31	35	31
Southland	14	34	34	21	32	51	36	48	34
Corvallis	11	20	26	19	20	34	-------	37	-------
Redheart	11	24	32	15	41	33	45	37	48
Missionary	10	31	38	24	39	46	49	50	51
U.S.D.A. 682	10	17	27	13	32	28	40	45	44
U.S.D.A. 1021	9	23	27	13	33	34	39	36	41
U.S.D.A. 512	9	26	33	12	30	36	45	43	30
Blakemore	9	23	30	14	40	33	41	41	46
Aroma	8	18	24	9	24	26	29	29	28
Dorsett	8	29	34	13	25	35	39	43	39
Howard 17 (Premier)	8	28	26	14	39	37	47	38	33
U.S.D.A. 652	7	25	28	10	32	30	40	47	45
Bellmar	7	24	30	15	38	32	43	43	48
Marshall	7	13	22	8	27	14	31	25	30
Fairfax	7	10	23	8	38	23	46	28	45
Dunlap	4	9	15	6	22	10	28	14	20

TABLE 4.—*Average length of petioles of all leaves produced from Nov. 17, 1930, to Feb. 1, 1931, and from Jan. 2 to Apr. 30, 1931, at Washington, D.C.*—Con.

Variety and species	Nov. 17, 1930–Feb. 1, 1931			Jan. 2, 1931–Apr. 30, 1931					
	Normal day	200-watt light	1,000-watt light	Normal day		200-watt light		1,000-watt light	
				October plants	January plants	October plants	January plants	October plants	January plants
	Cm	*Cm*	*Cm*	*Cm*	*Cm*	*Cm*	*Cm*	*Cm*	*Cm*
F. vesca (Erige du Poiton)	22	20	33	25	34	36	31	39	30
F. chiloensis (Reedsport, Oreg.)[1]	22	30	29	18	27	33	32	31	32
F. chiloensis (5-C)[1]	18	25	33	20	25	34	35	39	34
F. chiloensis (10—A)[1]	18	27	25	21	30	36	37	38	33
F. chiloensis (10-B)[1]	17	25	32	20	20	35	33	41	------
F. chiloensis (5-A)[1]	16	19	26	20	22	31	------	34	30
F. cuneifolia (Cox)[1]	16	20	26	25	21	27	27	31	------
F. cuneifolia (Rocky Mountains 9)[1]	15	23	23	19	26	29	31	27	29
F. moschata (var. M. Hautbois)	12	24	32	14	15	30	35	37	28
F. cuneifolia (14)[1]	10	21	22	14	23	29	21	32	23
F. virginiana (27)[1]	9	31	31	15	35	40	42	50	42
F. virginiana (N.Dak.)[1]	9	30	30	11	30	37	37	34	40
F. cuneifolia (Rocky Mountains 5)[1]	7	16	16	9	15	21	20	24	23
Average	11.4	23.7	27.8	15.6	29.4	32.1	[2] 36.5	36.6	[3] 36.2

[1] Accession number or source. [2] Average of 28 varieties. [3] Average of 27 varieties.

TABLE 5.—*Average number of new leaves produced by varieties and species from Jan. 2 to Apr. 30, 1931, at Washington, D.C.*

Variety and species	Normal day		200-watt light		1,000-watt light	
	October plants	January plants	October plants	January plants	October plants	January plants
Ettersburg 121	21	17	36	16	31	13
Dorsett	20	18	36	17	35	23
U.S.D.A. 542	20	14	22	14	30	12
Blakemore	15	12	14	10	17	12
Redheart	15	14	10	11	18	11
U.S.D.A. 1021	13	11	20	14	20	11
Fairfax	13	12	15	12	17	13
Southland	11	11	12	14	11	11
Corvallis	10	6	17	------	18	------
Howard 17 (Premier)	10	12	15	15	17	11
Missionary	9	9	13	8	21	10
U.S.D.A. 652	9	11	10	10	21	10
Bellmar	9	8	11	7	18	8
U.S.D.A. 682	8	9	13	10	12	10
Aroma	8	8	14	8	15	8
Marshall	8	8	8	8	11	8
Dunlap	7	9	7	10	9	9
F. vesca (var. Erige du Poiton)	37	15	32	26	53	20
F. cuneifolia (Rocky Mountains 5)[1]	35	20	44	30	74	36
F. cuneifolia (Rocky Mountains 9)[1]	32	22	50	14	92	20
F. cuneifolia (14)[1]	25	18	34	17	44	19
F. chiloensis (5-A)[1]	22	9	9	------	34	------
F. virginiana (N.Dak.)[1]	21	16	36	18	47	15
F. virginiana (27)[1]	20	9	25	9	23	9
F. chiloensis (Reedsport, Oreg.)[1]	18	9	16	9	17	10
F. chiloensis (5-C)[1]	18	10	11	9	10	11
F. chiloensis (10-A)[1]	16	12	12	10	16	14
F. moschata (var. M. Hautbois)	15	15	21	16	42	21
F. cuneifolia (Cox)[1]	13	11	22	14	39	------
F. chiloensis (10-B)[1]	9	9	11	9	15	17
Average	16	12	20	[2] 13	28	[3] 14

[1] Accession number or source. [2] Average of 28 varieties. [3] Average of 27 varieties.

As measured by the average petiole length of leaves produced up to February 1, many of the selections of species (*Fragaria chiloensis*, all 5 selections, and *F. cuneifolia* Nutt. (Cox)) grew much better than did any of the varieties, and the varieties adapted to southern States and the West (except Marshall) grew better than the northern and eastern ones.

When given additional light the petioles averaged over twice as long at the end of the test as when normal daylight only was used (23.7 cm as compared with 11.4 cm). Petiole length of new leaves produced under the normal light of late fall or in the winter seems to be one of the readily observable and easily determined measures of the adaptation of varieties. Varieties producing the longest petioles during this period are best adapted to sections with the shortest days at the time of fruit-bud formation in the Northwest and of fruit production in the South.

Petiole length and branching habit of the flower clusters have been found to be two very useful characteristics in judging varietal adaptation, even in the field. In the greenhouse, leaf and flower production in the winter can be used also.

As shown by the averages in table 5, more leaves were produced from January to April by the plants brought into the greenhouse in October than by the January series, whether under normal daylight, under the 200-watt or under the 1,000-watt lights. This was remarkable because the October plants produced nearly 60 percent more flowers during the same period. The number of leaves in the October series was least on the normal-day and greatest on the 1,000-watt plants; in the January series there was practically no difference in the various lots. The use of additional light on the average resulted in no increase in leaf number. In the October series the different varieties and species produced widely different numbers of leaves. Several selections of species produced more new leaves than did any of the varieties, and this held true for each light condition. Apparently no varieties respond as vigorously to greenhouse conditions as do some of the species tested. It may be significant that the relative numbers of leaves produced by the October plants of the selections from the Rocky Mountains where light is intense are much larger under the 1,000-watt lights (92 and 74) than those for other species and varieties.

The number of flowers produced by plants in the two series for the different light conditions corresponds closely with the number of new leaves produced. The January series produced about the same number of flowers in each lot and less than the October series. In the latter series there was an increase in number of flowers from the normal-light to the 1,000-watt lots. The number of flowers produced by Ettersburg 121 in the October series normal-day lot (64.3) and the number produced by the selection of *Fragaria virginiana* (N.Dak.) from North Dakota in the October series under 200 watts (52.5) and under 1,000 watts (154.8) are the most outstanding. The Ettersburg 121 produced the most flowers under the shortest days of winter without extra light, but *F. virginiana* (N.Dak.), produced the most when the extra light used was most intense.

RESPONSE TO DROUGHT AND CONTINUED FRUITING

Two specific effects of conditions noted are worthy of mention. The severe drought of 1930 in Maryland, which continued through the fall and early winter, prevented many plants from forming fruit buds and delayed fruit-bud formation in others. As a result fruit buds formed early on some varieties, late on some, and not at all on others. Early fruit-bud formation stunted the plants in comparison with late fruit-bud formation. This effect is sometimes seen under field conditions where the fruit bud has for some reason not formed or has been killed.

The second effect relates to a difference between plants brought into the greenhouse in October and those brought in in January. Figure 7 shows plants of these two series the following August. The plant

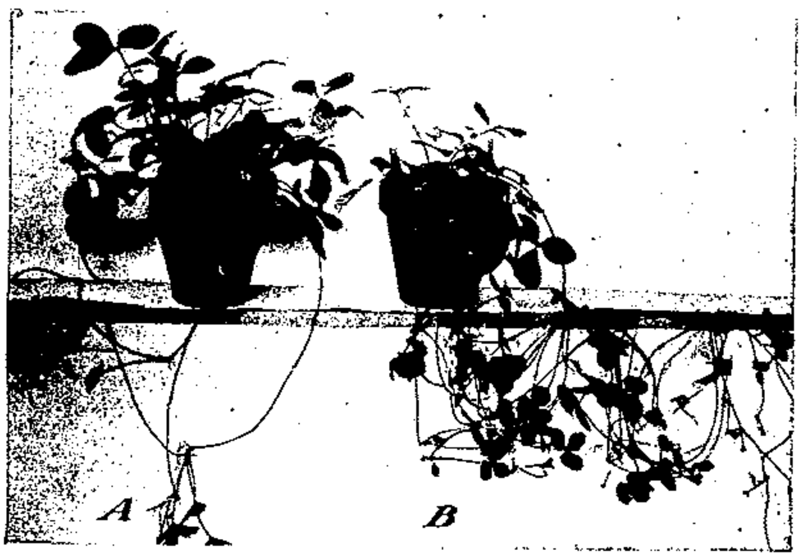

FIGURE 7.—*Fragaria virginiana* (27), grown in the greenhouse under normal daylight and photographed at Washington, D.C., August 1931: *A*, This plant was taken into the greenhouse in October 1930 before it had had a low-temperature rest period. It fruited throughout the spring and summer. *B*, This plant was taken into the greenhouse on January 2, 1931, after it had had a low-temperature rest period. It produced a crop in early spring, but thereafter it produced only runner plants.

to the left (October) continued fruit-bud formation during the winter, spring, and summer; while the plant to the right (January) developed only the fruit buds already started and from then on produced only runners and runner plants. The dormant period during November and December made such a change in the plants that no further fruit-bud differentiation took place. Similar effects in the field may be seen in the States from North Carolina south and along the coast in California. New plantings in those regions bear little or no fruit the first year, but having made fruit buds during the fall and winter, the plants tend to continue to form them during the short days of spring. In southeastern regions, with high summer temperatures near the coast, this tends to stop by July, but in the San Jose-Watsonville area along the coast in California, where it is rather cool, fruit-bud formation continues throughout the summer and fall and makes possible the highest yields known in the world.

The records of the relative quantities of berries produced week by week in 1928 and 1929 for the San Jose-Watsonville region of California are shown in figure 8. The graphs for both years show production peaks for May, the peak for 1928 being about 2 weeks earlier than that for 1929 due to a warmer April and May (2.6° F. higher average daily mean temperature for April and 2.4° higher average mean for May at San Jose). Following the production peaks, the graphs show low points for production for the last of June and during July 1929, but relatively higher points for the same periods in 1928. This late production came from fruit buds formed later than those which developed into the May and early June crop and apparently initiated during January, February, and March. An inspection of the temperatures at San Jose for these months shows mean temperatures below normal for each of the 3 months in 1929 and above normal for each in 1928. It may be, therefore, that mean temperatures for January, February, and March 1929 of 45.1°, 48.8°, and 53.4°, respectively, were too low and those of 48.6°, 52.2°, and 57.8° for the same months in 1928 were high enough to be favorable for fruit-

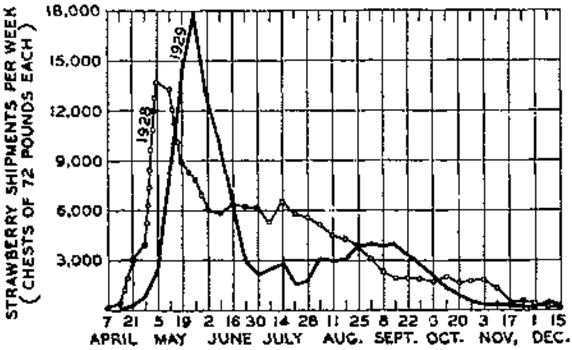

FIGURE 8.—Strawberry shipments per week from the San Jose-Watsonville area of California for 1928 and 1929, illustrating the effect of daily light periods and temperature in initiating fruit buds and in fruit production throughout the summer and fall. Shipments in chests of 72 pounds each.

bud initiation in the Marshall and Nich Ohmer varieties in the short-day lengths of winter there.

In western Oregon and Washington the summers are as cool as in the San Jose-Watsonville area, and but very little fruit is produced in the summer. It is cold enough so that the Marshall plants apparently become dormant in the winter, and when this dormant period is over more fruit buds are not ordinarily initiated. Moreover, the days are so long that fruit buds would not develop extensively. In the central valley of California where the days are the same length as in the coastal area, winter temperatures average lower than at San Jose, but the summer temperatures are so high that relatively little fruit is produced after early summer as compared with the San Jose-Watsonville area. In the Southeastern States where similar conditions occur, fall- and winter-formed fruit buds develop into the "ground" crop and spring-formed fruit buds develop into the "crown" crop, which lasts until hot weather in June or July stops their development. Apparently, therefore, fruit-bud formation is dependent on the relation between temperature and day length, and each variety may be assumed to have a characteristic response to day length and temperature.

The experiments of 1926 showed that night temperatures had a great effect on plant growth, and it is possible that definite ratios of daylight temperatures to those after dark for different varieties will be found which are most favorable for specific types of plant growth. In the studies reported in 1930 (*5*) there were indications that leaf growth was greatest when the night temperatures were more than 10° F. below optimum daylight temperatures. These studies have not indicated how important increased humidity with recovery of turgor, decreased respiration, or other conditions may be in this connection.

EFFECT OF LATE FALL ON THE SUCCEEDING CROP

The California production records and other evidence indicate that the fall conditions may have an important effect on the succeeding spring crop. If fruit-bud formation is initiated by definite temperature and daily light relations, then the extent of fruit-bud development should be determined by the length of time the favorable relationship continues. This is proved by the production records in Florida as well as in California. In Florida fall conditions are continued to an extent throughout the winter; the fruit buds develop into flowers, the flowers into berries, and the berries are harvested from December to June. In nearly every section fall seasons have been known where fruit-bud formation and development continued until late and the flowers opened; sometimes even the fruit ripened.

Although the late falls may result in some flowers opening and being killed, many growing points which might have continued as vegetative buds become fruit buds and the longer the fall growing period the greater the spring crop. Waldo (*15*), however, has shown that fruit buds of different varieties tend to develop at different rates, which has often obscured the effect of late falls.

Moreover, varieties start their rest periods under different temperature-light conditions. In the Willamette Valley of Oregon the Marshall begins fruit-bud differentiation about September 1 but becomes relatively dormant with the first hard frosts. The Ettersburg 121 variety, however, starts making fruit buds late in October and continues throughout the winter (*6*). Late mild fall seasons favor extensive fruit-bud development in the Marshall, whereas a mild winter favors it in the Ettersburg 121.

The leaf area for 16 kinds under normal daylight after about 3 months (Nov. 11 to Feb. 7) in the greenhouse was as follows:

Average leaf area, on February 7, 1931, of strawberry plants put in the greenhouse November 11, 1930, at Corvallis, Oreg.

Variety or species:	*Leaf area, cm^2*	*Variety or species*—Continued.	*Leaf area, cm^2*
U.S.D.A. 911	290	Southland	130
Wickson	211	Missionary	128
Redheart	207	Blakemore	99
Fragaria chiloensis (10-B)	197	U.S.D.A. 682	92
U.S.D.A. 1021	181	Bellmar	82
Corvallis	166	Clark	76
Ettersburg 121	159	Marshall	66
Howard 17	138	Dunlap	26

It should be noted that U.S.D.A. 911 (Kalicene×Rockhill), Wickson, Redheart, *Fragaria chiloensis* (10–B), U.S.D.A. 1021 (Kalicene ×Howard 17), Corvallis, and Ettersburg 121 with the greatest leaf area are derived wholly or in part recently from the wild *F. chiloensis;* whereas Dunlap, Marshall, Clark, Bellmar, U.S.D.A. 682, Blakemore, and Missionary, which have the least leaf area in this series, are not derived recently from *F. chiloensis*. The first 7 sorts had 147 percent more leaf area than the second 7 varieties. Vigorous growth response under the short days of midwinter in cultivated varieties is inherited from *F. chiloensis* (fig. 9); Missionary and Blakemore of the second

FIGURE 9.—Growth of strawberry species and varieties under normal light from November 11, 1930, to January 31, 1931, Corvallis, Oreg.: *A*, Species *Fragaria virginiana*, *F. cuneifolia*, *F. chiloensis*, and *F. californica; B*, varieties Clark, Dunlap, Corvallis, and U.S.D.A. 1021. Considerable growth has been made by *F. chiloensis*, *F. californica*, Corvallis, and U.S.D.A. 1021. The latter two varieties have descended in part recently from *F. chiloensis* and respond much like it. The others, Clark and Dunlap, respond more like *F. virginiana*.

lot of 7 are especially adapted to relatively short-day regions in the Southeast, probably inheriting this characteristic from *F. virginiana*.

In table 6 is given the average leaf area on April 7, 1931, of nine varieties and species of strawberries which were grown at Corvallis, Oreg., under daily light periods ranging from normal light of winter to continuous light under 500-watt lights only. There is little evidence in this table of the relative value of the 4- and 7-hour exposures for different sorts from the leaf area records taken after 3 and 5 months. Both Ettersburg 121 and Blakemore, however, had considerably greater leaf area under the 7-hour than under the 4-hour exposure. Exposure for 14 hours on the average resulted in distinctly less leaf area, while continuous exposure to electric light resulted in the poorest growth of any (fig. 10). Under continuous exposure to 500-watt lights only, Marshall, *Fragaria cuneifolia* (14), Blakemore, Howard 17, and Ettersburg 121 produced flower buds and flower clusters; whereas only *F. cuneifolia* (14), Ettersburg 121, and Missionary produced runners.

FIGURE 10.—*Fragaria chiloensis* (10-B). *A*—*a*, Normal-day plant November 11 to February 5; *b*, normal-day plant January 8 to February 5; *c*, plant grown with normal daylight plus 500-watt lights for 7 hours each night, November 11 to February 5. This selection has developed best under the normal light in midwinter. Photographed February 6, 1931, at Corvallis, Oreg. *B*—*a*, Normal-day plant; *b*, plant grown with normal daylight plus 500-watt lights for 4 hours; *c*, plant grown with normal daylight plus 500-watt lights for 7 hours; *d*, plant grown with normal daylight plus 500-watt lights all night; *e*, plant grown with continuous 500-watt lights only from November 11 to April 9, 1931. Photographed April 9, Corvallis, Oreg. After the days lengthened toward spring the plants grown under 500-watt lights for 7 hours (*c*) and for all night (*d*) produced many runners.

TABLE 6.—*Average leaf area on Apr. 7, 1931, of 9 strawberry varieties and species at Corvallis, Oreg., under normal daylight, under normal daylight plus 4, 7, and 14 hours of 500-watt electric light, and under continuous 500-watt lights only*

Variety or species	Nov. 11 series					Jan. 8 series				
	Normal light	+4	+7	+14	24 hours	Normal light	+4	+7	+14	24 hours
	Cm²	*Cm²*	*Cm²*	*Cm²*	*Cm²*	*Cm²*	*Cm²*	*Cm²*	*Cm²*	*Cm²*
F. chiloensis (10-B)	405	284	273	144	0	238	151	220	188	109
F. cuneifolia (14)	332	168	218	105	170	176	176	318	161	97
Ettersburg 121	321	234	377	322	161	214	303	399	159	151
Howard 17	317	224	301	295	142	255	230	344	248	210
Missionary	290	259	204	249	120	279	306	233	106	126
F. chiloensis (Hawaii)	280	-----	194	-----	-----	130	-----	150	-----	-----
Blakemore	280	233	341	186	112	158	139	309	250	142
Marshall	227	391	226	108	145	185	102	295	157	89
F. virginiana (27)	178	300	151	201	117	217	-----	-----	-----	-----

The leaves of all sorts were small and thin with long petioles and were dark green in color under continuous light. It is possible to grow strawberries for long periods under artificial light though it is apparent that exposures to 500-watt lights at the temperatures used (averaging about 60° F.) do not result in normal growth.

On September 1, 1931, before the fruit buds of most sorts had started, 4 to many plants each of 5 varieties and species were brought into the greenhouse at Corvallis, Oreg. Half the plants were exposed to 500-watt electric lights until 10 p.m. each night in addition to daylight throughout the fall and winter, the other half received only the normal light of fall and winter. The temperature was for the most part 60° to 70° F. These plants formed few fruit buds, either under the normal daylight or under normal daylight plus electric light, until December. By January 15, however, the normal-day and the additional-light lots began to show the differences owing to the length of day. The normal-day plants had averaged over a flower cluster each, whereas only a few of the plants under the daylight plus 500-watt lights had produced flower clusters. By February 15 the normal-day plants had averaged 3.8 clusters each, and the daylight plus 500-watt plants only 0.7 cluster per plant. By June 9 the control plants had averaged 20.2 clusters, but those receiving daylight plus the lights had averaged only 4.8 clusters each. Thus lengthening the daily light period beginning September 1 in general continued the vegetative condition and stopped fruit-bud formation in many varieties and selections of species.

The plants of these 51 varieties under normal daylight produced flower buds, but only in December after 3 to 4 months. In the field most fruit buds are formed in September and October. Apparently the formation of fruit buds is affected by low temperatures as well as by the length of the daily light periods. In the field with short days and low temperatures, fruit buds form quickly; but if the temperature is kept near 60° F. they form after several months instead of after a few days, or in some varieties at most a few weeks as they do out of doors. Different varieties responded differently and undoubtedly have characteristic temperature daily light period responses, some few even forming fruit buds at temperatures about 60° F., as in the experiments 1923 to 1926.

Growth on all the plants was nearly normal, although in the normal-day series the petioles were short and the size of the leaves small as compared with the daylight plus 500-watt plants. Some varieties even produced more new leaf area under the normal-day than under the additional light conditions. When records of all five varieties were averaged, however, the increased leaf area due to the added light was 3.6 percent by October 15, 31.6 percent from October 15 to December 6, and 37.2 percent from December 6 to January 15. The successively smaller size of the new leaves on the normal-light plants is characteristic of plants in process of changing from a vegetative to a fruiting condition. This temperature-day-length complex induced a slow change from a highly vegetative to a fruitful condition.

DISCUSSION

RESPONSE OF SPECIES TYPES

The species that represents the group from which other species have probably evolved is *Fragaria vesca*. Neither it nor its close relatives (*F. vesca semperflorens*, *F. vesca californica*,[5] and *F. vesca alba*) show daily light requirements comparable with other forms. *F. vesca* is native and adapted to regions from the Arctic Circle nearly to the Equator and from high mountains to sea level. It made greater growth under the longer daily light periods but was able to make a fairly vigorous growth under the shortest light periods of midwinter in the low light intensity of the greenhouse at Washington. However, some of the other forms or species allied to *F. vesca* have more specialized requirements. It would seem that such allied species have evolved from *F. vesca* or from a prototype of that species having a similar light response.

The few forms of *Fragaria moschata* studied show less response to long daylight periods than most cultivated varieties but are more

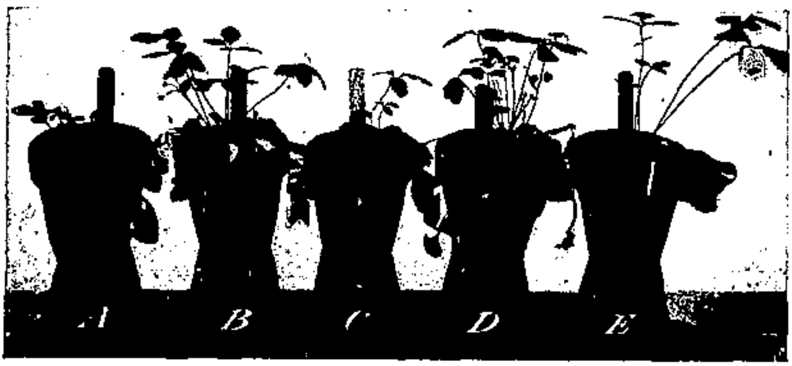

FIGURE 11.—*Fragaria virginiana* (27): *A*, Under normal light of winter at Corvallis, Oreg.; *B*, normal light plus 4 hours daily of 500-watt lights; *C*, normal light plus 7 hours of 500-watt lights; *D*, normal light plus 500-watt lights dark to daylight; *E*, 500-watt lights only for all 24 hours. Note the slight growth of *A*, vigorous growth of *B* and *D*, the ripening fruit on *C*, and the very slender growth of *E*.

responsive than *F. vesca*. *F. moschata* is a native of central Europe, while allied forms are found in central Asia. The allied form of *Fragaria* sp., introduced by Harlan from Kashmir, was particularly responsive to longer light periods.

The forms of *Fragaria virginiana* (fig. 11) used in these studies showed greater response to longer daylight periods than *F. moschata* and *F. vesca*, while some of the forms of *F. chiloensis* (fig. 10) were apparently best adapted to short days; others showed some response to longer light periods than normal in midwinter. Selections of *F. chiloensis* growing freely under short days may be especially valuable for use in breeding varieties for southern regions where berries are shipped during the winter months and also in breeding varieties for regions with winters sufficiently mild so that fruit buds can develop throughout the winter as in parts of the Pacific Northwest.

[5] **Fragaria vesca californica** (Cham. and Schlecht.) Darrow and Waldo. *F. californica* Cham. and Schlecht., Linnaea 2: 20. 1827.

Figure 12 illustrates the difference in the length of day in different strawberry regions. At the bottom are bars to represent the length of daily light and dark periods at Plant City, Fla., on January 1 and June 21, and at the top are similar bars for Alaska. There is just a little over 2 hours' difference in the length of the daylight period in winter and in summer at Plant City, while in Oregon and Washington between sunrise and sunset there is a difference of about 7 hours, plus an additional 1 to 2 hours of effective twilight before sunrise and after sunset.

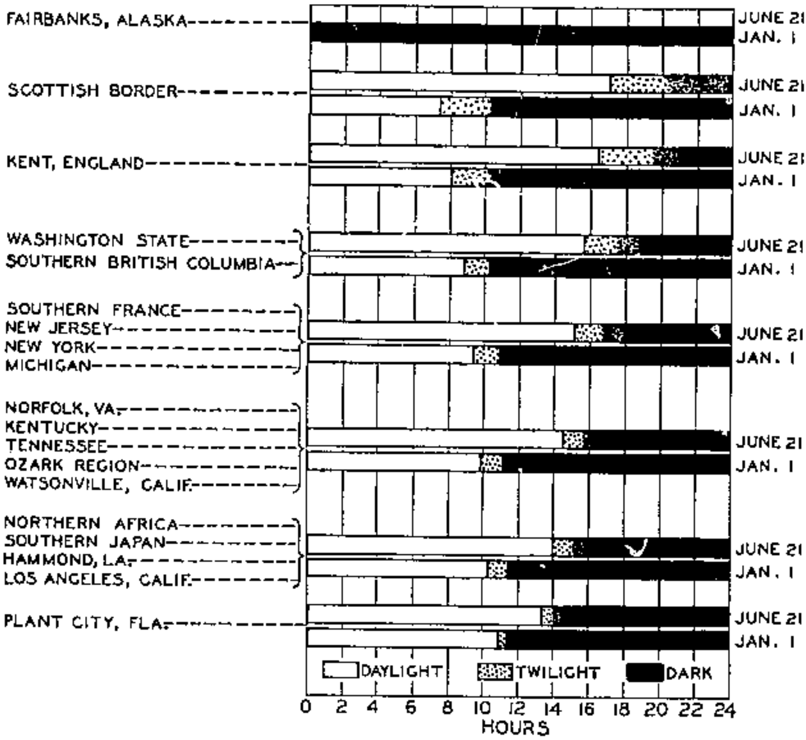

FIGURE 12.—The length of the daylight period for the several strawberry-growing regions on January 1 and June 21 is represented by the length of the uncolored bars, the length of the twilight effective for plant growth by the dotted bars, and the length of the night by the black bars. Thus on June 21 the daylight period was 24 hours long at Fairbanks, Alaska; the light effective for growth about 20 hours long in the berry region of southern Scotland; in southern British Columbia and Washington State nearly 18 hours long; in New York about 17 hours; at Norfolk, Va., nearly 16 hours; at Hammond, La., about 15 hours, and at Plant City, Fla., about 14 hours. At Plant City, Fla., on January 1, when berries are ripening, the daylight period is 11 to 12 hours long in contrast to 24 hours of daylight at Fairbanks, Alaska, on June 21, when the plants are flowering there.

Fragaria chiloensis is native to the Pacific coast from Alaska southward to central California and in the higher mountains of the Hawaiian Islands. Thus, forms of this species are native where there are nearly 24 hours of daylight during several weeks of summer (Alaska), and also where there are about 12 hours of daylight the year through (Hawaii). With a species as variable as this it might be expected that forms suited to different day lengths might be found, and this has proved to be the case. In these tests several forms have grown well under short days.

In figure 9 are shown four species under normal light of winter at Corvallis, Oreg. *Fragaria chiloensis* (10-B) shows much the best growth, *F. vesca californica* the next, followed by *F. cuneifolia; F. virginiana* (27) shows the least growth.

RESPONSE OF VARIETIES

Cultivated varieties of strawberries are derived chiefly from *Fragaria chiloensis* and *F. virginiana* but show an even greater range of response to differences in daily light exposures than do the forms of the species used in these experiments. Under field conditions varieties are raised in Alaska where they have continuous light for about 6 weeks in summer, southward to high altitudes in the Tropics where the daylight periods are about 12 hours throughout the year, and in Florida where in winter the daylight periods are 10 to 11 hours long. Cultivated varieties are grown over a greater range than the native habitat of the parent species—a little farther north than the northern limit of *F. chiloensis* in Alaska and farther south below the Equator in South America. In the light experiments some varieties grew well in summer with light periods only 10 hours long; others grew fairly well in the greenhouse with the periods as short as 9 hours.

In the experiments of 1924 to 1926, under field conditions of high light intensity and high temperatures in summer, growth continued under 8½ to 9 hours of light; in the summers of 1927 and 1928 growth continued under 10 hours of light in boxes; while in 1928 to 1932 in the greenhouse some varieties grew even under the 9-hour day of low light intensity of midwinter. In 1931–32 plants of 52 varieties and species which were put in the greenhouse September 1 lived and some grew during the period December 6 to January 15 under normal light. A base line for growth regarding the duration of light will therefore vary with variety, temperature, light intensity, previous conditioning, and possibly with other conditions such as light quality.

Some varieties make no growth in the greenhouse in winter at any temperature under 9-hour daylight periods but in summer grow under 9-hour periods, or in winter grow if kept at a temperature of 60° F. or above from September 1, or if first exposed to low temperatures to break their dormant periods. Other varieties grow nearly normally even under 9-hour light periods in the greenhouse. The base line for growth for the latter sorts must be nearer 8 hours of light in winter and possibly still lower in summer.

The type of growth made by the several varieties differs also with the duration of the light periods. When the summer days were shortened to 10 hours runner production disappeared almost altogether. Shortened summer days seemed to cause the crowns to branch instead of producing runners. These branched crowns eventually differentiated fruit buds, which at least partially accounts for increased flower production the following spring (table 1). In the winter tests of 1929–30 no variety produced runners except when additional light was given. Under 200-watt lights to supplement daylight Bedarena and the southern varieties, Missionary and Blakemore, were the first to produce runners. Thus with light periods just above the base line for growth and under favorable temperatures for the variety the growing points differentiate into fruit buds. With similar light the growing points develop into branch crowns. With daily light periods still farther above the base line the growing points develop into runners.

The fruit clusters developed by the buds of varieties adapted to growth in short days may become very large and branch basally (*3*) when developed in short days, but when the daily light period is lengthened under greenhouse conditions the peduncles grow very long. It seems probable, therefore, that if the plants are vigorous and conditions are suitable for relatively slow development when a variety forms its fruit buds the fruit cluster will be large and basal branching with a maximum of large berries. Under field conditions in the northern part of the range of any variety the clusters tend to be high branching and relatively small, while to the southward they tend to be low branching and large. Since the daily light periods shorten more slowly in regions of the latitude of North Carolina than in New York, the clusters of most varieties should be larger and tend to basal branching in North Carolina more than in New York. Observations on several scores of varieties in both States confirm this. The Dunlap and Howard 17 are northern sorts and produce basal-branching clusters farther north than such southern sorts as Missionary, Klondike, Blakemore, and Bellmar.

The terminal cluster is the first to differentiate in the fall and in the cool weather it has the longest time to develop; hence, in general it should be, and observations confirm that it generally is, the largest. Fruit buds of the Missionary formed in the spring in North Carolina usually develop into high-branching "crown" clusters apparently because the days are lengthening and the warmer weather induces more rapid development. Farther south in Florida where the fruit buds grow slowly throughout the winter they develop into basal-branching clusters; later in the spring the clusters develop more quickly and become high branching.

It has been commonly observed that the leaves developed by strawberries in the fall average much smaller and have very much shorter petioles than those produced in midsummer. Similar differences were noted in these studies of the effect of length of the light periods. The leaves of the long-day plants were often more than four times the size of those grown in short days; reference to table 4 shows that the long-day petioles were sometimes as much as five times as long as those of the short-day plants.

The responses of *Fragaria vesca semperflorens* and of Mastodon indicate that they represent wholly different groups of everbearing strawberries. *F. vesca semperflorens* grew vigorously under the very short days of midwinter; it blossomed and was the only strawberry that produced runners under the short days of winter up to March 11, 1930. On the other hand, Mastodon plants actually decreased in size under the short days and low-light intensity, and not even in the lots exposed to daylight plus 1,000-watt lights for half the night did it make a normal growth like that of summer. Fruit-bud differentiation and vigorous growth in the Mastodon take place in the long warm days of summer, while *F. vesca semperflorens* apparently is relatively indifferent to either condition.

RELATION OF PHOTOPERIODISM TO THE REST PERIOD IN THE STRAWBERRY

These experiments on the light requirements of strawberries have suggested a cause of the rest period in the strawberry and possibly in other plants (*11*). The strawberry plant in northeastern United States becomes more or less dormant with the onset of short days and low temperatures of fall just as do most other plants of temperate regions. The experiments referred to above have shown two effects of the low temperatures on the strawberry. In one experiment, plants that were placed each night from dark till dawn in a cold-storage room held at about 45° F. grew far more vigorously than those left outside at summer night temperatures; in other experiments plants first exposed to a low-temperature rest period in late fall have made greatly increased growth. Thus, strawberry plants that were given a rest period by being left out of doors late in the fall and brought in about January 1 when the days were still short grew vigorously without additional light. Although the days were actually shorter in some of the tests, as much growth was made by some sorts and more by many sorts in 4-weeks' time than in 12 weeks when plants were brought in early in November. No low-temperature exposure at any light intensity or duration at any time in spring, summer, or fall has ever been observed to induce a rest period.

Varieties grown near the Equator in the Andes Mountains in Ecuador are sufficiently adaptable to grow and fruit continuously under light periods that prevail there (*13*); in such regions a dormant period is not required. Their continued growth and fruiting seems to be correlated with a relatively constant exposure to the photoperiodic and temperature requirements of the particular variety. Growth in some form apparently can continue over a fairly wide range of daily light exposures from less than 9 to 24 hours. However, in the latitude of Washington, D.C., even varieties adapted to very short days show somewhat better growth in the greenhouse when exposed to low temperatures for a time than if put into the greenhouse late in October after the days become short but before the advent of cold weather. Plants of such varieties raised in Maryland and shipped to Florida in October do not usually make as vigorous a growth as plants raised in Florida, where the days are not as short as in Maryland from October onward. Exposure to the relatively short days of late summer and early fall up to October has apparently effected such a change in the plants that a rest period is beneficial. Most varieties adapted to northern regions make little growth when the daylight periods are 10 hours or less in duration. If first given a low-temperature rest period, however, they grow vigorously in the greenhouse during midwinter, when the days are less than 10 hours long. For these varieties adapted to long summer days, a low-temperature rest period is necessary for renewal of vigorous growth under normal winter days in the greenhouse.

Plants of 51 varieties placed in the greenhouse September 1 and exposed to electric light until 10 p.m. in addition to daylight did not become dormant. Exposure to short daily light periods, therefore, seems to induce a rest period in many varieties of strawberry (*10*).

These studies of response to light show that the strawberry varieties now grown in regions of relatively short and of relatively long days have actually been selected for their adaptation to the light and rest period conditions of those regions.

Garner and Allard (*11*) reported that by increasing the daily light period in September before the leaves dropped, the tuliptree was enabled to renew active growth. Two kinds of sumac, however, did not resume active growth. They concluded that "the decreasing length of day is an important factor in causing perennials to enter upon the winter period of dormancy." The tuliptree in September apparently corresponds to certain strawberry varieties that have ceased active growth in October, but that can resume active growth if the daily light exposure is increased. The sumac in September seems to correspond to these same varieties of strawberries in November and December after longer exposure to short days at temperatures permitting growth. They then need a low-temperature rest period before they can resume vigorous growth However, if the sumac and other plants responding similarly had been exposed to a suitable day length some time before they had formed terminal buds, they might have continued growth indefinitely.

It is here suggested that the rest period in the strawberry (and possibly in other plants of temperate regions) may be a result of nutritional conditions caused by relatively short daily light periods and relatively low growing temperatures. This conception of the relation of daylight periods to the rest period may explain the different responses of the same variety of strawberry and possibly of other evergreens and even of some deciduous shrubs and trees when transplanted from widely different latitudes. If transplanted in the fall from northern to southern latitudes the northern plants may be expected to be more dormant than the southern-grown plants, and, as with the strawberry, not grow so vigorously. Such plants must truly get acclimated. On the other hand, plants propagated in regions of high temperatures and short days, as Florida and southern California, may suffer from lack of cold weather to break their partial dormancy.

In tests of selections from the breeding work of the United States Department of Agriculture, the results have been remarkably enlightening even though it has not yet been possible to combine daily light tests with different day and night temperatures. The Blakemore has not grown as well as the Missionary in the short days of low light intensity of winter, and this may be interpreted to indicate that it will not succeed as well in Florida as the Missionary. In actual tests in Florida, this seems to be borne out. In the long days the Blakemore has made more vegetative growth and less fruit than Howard 17, and again its field response in the North has agreed. It seems to be adapted to the region between the southernmost part of the Missionary and northernmost part of the Howard 17 regions. Two new sorts, Dorsett and Fairfax, have been introduced for the latitude of Maryland to New Jersey. In their responses to conditions the Dorsett has tended to resemble the Blakemore and the Fairfax the Howard 17. This is interpreted to mean that the Dorsett will be adaptable to regions farther south than those in which the Fairfax will be adapted. Actual field tests in western North Carolina have already shown the Dorsett to be much better adapted to that region than the Fairfax.

SUMMARY

Everbearing varieties of strawberries are "long-day" plants, forming fruit buds under the long days of summer in the Northern States.

Ordinary varieties of strawberries are "short-day" plants, rarely forming fruit buds under natural conditions except in the fall, when the days become short and the temperature low.

Runner formation does not occur with a 10-hour day in summer in ordinary varieties or in a few varieties with a 12-hour day.

Branch crowns tend to form when the daily light periods become too short for runner formation.

Fruit buds tend to form when the daily light period becomes still shorter than for optimum branch-crown formation.

Daily light periods of 8, 10, and 12 hours in summer and early fall resulted in an increase in the number of blossoms produced the following spring.

Increasing the daily light periods by the use of artificial light did not induce full normal growth in plants brought into the greenhouse from October through December, but did induce growth approximating normal if the plants were brought in September 1 or before fruit-bud formation had started.

When brought in from winter conditions after January 1, growth of most varieties was approximately that of summer whether the plants were given additional light or not.

Varieties are considered to have characteristic temperature-day-length responses which determine their regional adaptation.

Southern varieties grow under short days at relatively low-growing temperatures and need little rest or no dormant period.

Northern varieties grow very little under short days and, if first exposed to short daily light periods, require a low-temperature dormant period to break their rest period.

The rest period in the strawberry is considered to be caused by a short-day low-temperature complex and is broken to a degree in some varieties by additional daily light exposures and in all varieties by temperatures at or below freezing.

Plants of over 80 varieties and species when not given a full rest period continued flowering and fruiting in the greenhouse until July, and some at least continued until August; the same sorts when given a rest period formed no fruit buds after the rest period.

The response of varieties to light conditions during October, November, and December is considered indicative of their regional adaptation. Varieties adapted to southern States produce relatively large leaves with long petioles, while northern varieties grow little or not at all during these months.

In southern States fruit clusters become large and branch basally when developed from fruit buds formed under short daily light periods of fall and early winter, but late-winter and spring-formed fruit buds usually develop into high branching clusters.

In these experiments fruit clusters produced in the greenhouse under long-day conditions from fruit buds well developed before being brought into the greenhouse branched basally while later clusters were high branching.

Transformation of vegetative growing points into fruit buds under normal daily light conditions from September to January occurred at

temperature, averaging about 60° F., but started at a slow rate compared with usual outdoor plants in the Eastern States.

At temperatures above 60° F. short daily light periods (10 hours or less) are necessary to initiate fruit buds and may initiate them in a few varieties only; at low temperatures fruit buds may form under longer daily light periods.

Many strawberry varieties grew fairly well for 5 months under continuous artificial light only.

Late falls are considered favorable to extensive fruit-bud development and to increased crops in the succeeding spring.

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