EFFECT OF PHOTOPERIOD AND OTHER FACTORS ON THE DEVELOPMENT OF SOME SHORT-DAY PLANTS

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INTRODUCTION

The development of the concept of photoperiodism by Garner and Allard (4, 5, 6) reintensified the experimentation on the effect of external factors on the development of plants which began with Klebs (11) and was popularized in the United States by Kraus and Kraybill (12). Working from the concepts of Kraus and Kraybill, Loomis (14) has attempted to classify plant reactions under the two headings of growth, which includes cell division and enlargement, and differentiation, which covers all other phases of development. Fruiting is considered by Loomis to be an alternation of the differentiation of flower buds, growth of flowers, differentiation of spores, and growth of gametophytes and later fruits.

The concept of photoperiodism does not fit readily into such a scheme of plant development, and this study is intended to explore the interrelations of photoperiod, or relative length of day and night, and of other factors which might be expected to affect differentiation.

REVIEW OF LITERATURE

Garner and Allard (4, 5, 6) have shown the importance of photoperiodism in relation to the growth responses of plants and performed the basic experiments on the problem. Hamner (7) gives an excellent review of early work. Since the publishing of his paper, Long (13) has showed the effect of variation of light intensity, temperature and humidity upon the length of the critical dark period for Biloxi soybeans (Glycine Max). In his experiments Biloxi soybeans flowered only after exposure to consecutive, long, dark periods, each alternating with a short light period, and plants did not flower regardless of the number of long dark periods they received, unless at least three of the dark periods were in consecutive order. In order to produce a second group of flower primordia the plants had to be exposed to another induction period of three or more long dark periods. Borthwick and Parker (1), illustrating the photoperiodic responses of several soybeans, state that old Biloxi soybean plants initiated flower primordia on light periods longer than 16 hours, but that 12-14 hours of light was the critical upper limit for normal flowering and fruiting.

The influence of the duration of the daily photoperiod upon reproductiveness is the outstanding, but by no means the only effect of this climatic factor on growth. Some of its other more important effects are upon: (1) rejuvenation (Garner and Allard, 5), (2) sexual expression (Schaffner, 17, 18), and (3) production of storage organs (Zimmerman and Hitchcock, 19).

The observations of many investigators indicate that the carbohydrate content of plants, in relation to the amount of nitrogen available, strongly influences the type of growth which is made, particularly since the work of Kraus and Kraybill (12). Working with tomatoes, these investigators found that flowering and fruiting can only take place when the carbohydrate and nitrogen content of the plant lies between certain limits. In their analyses a correlation between the change of the carbohydrate-nitrogen ratio and the sequence of reproduction activities appeared to exist, whether this ratio was the cause or the effect of the reproductive sequence. As a result of their studies, this carbohydrate-nitrogen hypothesis has found wide acceptance. Nightingale (16) and others, however, clearly show that there is no simple or consistent relationship between the ratio of nitrogen to carbohydrate and the growth response of the plant. On the other hand, experience of growers and research workers is adequate evidence that there is a relationship between the commercial fertilization of an apple orchard and its fruiting. Loomis (14) has shown in his work that growth-differentiation balance differs from the carbohydrate-nitrogen balance in (a) assigning an independent and major role to moisture, (b) including with nitrogen the other equally essential if not so commonly limiting factors concerned in the synthesis of protoplasm, (c) recognizing the effects of temperature, and (d) emphasizing the importance of active carbohydrates as opposed to storage forms. He states this concept only as a convenient and simplified scheme for predicting or explaining plant behavior.

MATERIALS AND METHODS

Materials

Plant materials used in these experiments were grown in the greenhouse at Ames, either in flats 4 inches deep or in 8-inch pots. The Biloxi soybean seed was furnished by Dr. A. D. Suttle, Professor of Agronomy at Mississippi State College. The Cosmos and Salvia seed were commercial stocks purchased from local dealers.

Methods

The purpose of the study was to compare photoperiodism with differentiation induced by stunting. Plants were grown accordingly in two groups, one with fertile soil, high moisture and a double cheesecloth shade to reduce the greenhouse light to 40 per cent, and a second group in poor soil, lower moisture and full greenhouse light. Plants from each group were then given the normal April to August day length of 14 to 16 hours, or were transferred daily to a dark room at 5:00 p.m. and returned to the greenhouse at 8:00 to 9:00 a.m. for a short day of 8 to 9 hours.

The "fertile" soil was composed of 1½ bushels of sod and manure compost thoroughly mixed with 2 pounds of superphosphate

(17 per cent P_2O_5) and one pound of ammonium sulfate. The low fertility soil was prepared by mixing one part of compost and three parts of river sand. High moisture pots were watered daily to optimum moisture. Low moisture pots were watered lightly to prevent wilting.

Observations included:

Height of plant growth

Density of plant growth

Health

Time of flowering

Root development

Dry weight differences

Quantitative analyses of selected samples

In all there were 8 groups of 8 pots each in the 1935 experiments, 4 groups for the Cosmos and the same number for the soybean. The soybeans were kept on one side of the bench in the greenhouse to themselves while the Cosmos were placed on the opposite side. This arrangement prevented any shading between the different plant groups. However, the plants of all groups were close enough together to have similar exposures of sunlight. The central bench was used for the best light advantage.

Factors Influencing the Growth of Plants

Group I

Low light intensity
High soil moisture
Fertile soil
Long day

Group II

Low light intensity
High soil moisture
Fertile soil
Short day

Group III

High light intensity
Low soil moisture
Medium fertile soil
Long day

Group IV

High light intensity
Low soil moisture
Medium fertile soil
Short day

In addition to the regular groups a second set of experiments was run on the Cosmos and soybean. These experiments used seedlings grown in river bottom sand in flats; three flats of Cosmos and three flats of soybeans. Instead of watering these flats with tap water, a manure compost extract was used. This was prepared by placing a shovel of horse manure in a five gallon crock and covering with tap water. The process was repeated to supply additional water for the flats.

The flats were treated as follows:

Flat I

Optimum amount of water
Low light intensity
Long day

Flat II

Optimum amount of water
High light intensity
Short day

Flat III

Optimum amount of water
High light intensity
Long day

In the early part of this experiment, the seedlings of the Cosmos began to "damp off". This condition was corrected by spraying the soil with a weak solution of organic mercury. The solution was made by dissolving a gram of mercury dust in a gallon of water. After an application of this spray to the top soil there was no further evidence of "damping off".

During the spring of 1938 this experiment was repeated except that the growing of plants in flats was omitted. At this time Salvia was grown instead of Cosmos.

Sampling and Preserving

The material for chemical analyses was gathered and divided into duplicate samples of 25 to 75 grams. All plant parts, whether leaves, stems, fruit or roots, were handled as rapidly as possible to avoid enzymatic changes. The samples were weighed, cut into 2- or 3-mm. sections and dropped into mason jars containing 500 cc. of boiling 95 per cent ethyl alcohol. The jars containing the samples were placed on a boiling water bath and allowed to simmer for 30 minutes. At the termination of this period, the jars were sealed tightly and set aside until extractions were made.

The material was extracted 20 times by decentation with 80 per cent redistilled ethyl alcohol. Further extractions showed the process to be complete. The combined extracts were made to volume (1000 or 2000 cc.) at 20 degrees C. The insoluble residues were dried and weighed, after which they were ground in a Wiley mill and then in a ball mill until the material was in a powdered form. The residues were stored in tightly sealed bottles for polysaccharide and insoluble nitrogen determinations. The extracts were used for determinations of sugars and soluble or non-colloidal nitrogen fractions.

Methods for the Analysis of Plant Material

One-tenth aliquots of the alcoholic extracts were transferred to water, cleared with neutral lead acetate, deleaded with anhydrous sodium oxalate, and reducing sugars determined by a modification of the Munson-Walker and Bertrand methods. Sucrose was hydrolyzed with invertase and determined as invert sugar (15).

The total nitrogen of the alcoholic extract was determined by the unmodified Kjeldahl method and reported as non-colloidal or soluble nitrogen. Total nitrogen of the alcohol insoluble residue is reported as colloidal nitrogen and considered to be a measure of the protein content of the tissues.

EXPERIMENTAL RESULTS

Growth and Flowering Responses

Experiments with Cosmos

In a series of experiments with Cosmos plants observations were made on the general growth of the plants in height, branching, first blossom date and color of leaves during a limited growth period.

Plants grown in poor soil watered with liquid manure, and receiving varied treatments of light intensity and photoperiod from June 28 to August 22, 1935, showed differences in their growth responses as shown in table 1. Plants exposed to a 15-16 hour photoperiod at low light intensity elongated most but showed no evidence of flowering. These plants produced the greatest area of leaves. Plants receiving long days but exposed to a greater light intensity did not grow quite as tall, did not produce as much leaf area, nor did they show any indication of flowering during this growth period. Plants given a short photoperiod with high light intensity developed less elongated stems but differed from the above mentioned groups by producing flowers in 46 days.

In another experiment with Cosmos plants given different treatments of light intensity, moisture, fertility and photo-

Table 1. Observations on the Growth of Cosmos.

(All plants in flats watered with liquid manure)
(Seed planted June 28; final records Aug. 22, 1935)

Day length (hours)	Light intensity f.c.*	Soil		Ave. height (inches)	First blossom date	Leaf starch test	Condition	
		Moisture	Fertility				Growth of plants	Color of leaves
15-16	3,200	High[t]	Low	12.0		Positive	Most leaf area	Light green
8-9	8,000	"	"	7.0	Aug. 13	"	Buds in crown of plants	Yellow green
15-16	"	"	"	9.5		"	Medium leaf area	Green

* Midday with clear sky
t Soil kept moist

Table 2. Observations on the Growth of Cosmos
(All plants in 8 inch pots - seed planted June 28 - final records Aug. 22, 1935)

Day length (hours)	Light intensity f.c.*	Soil: Moisture	Soil: Fertility	Ave. height (inches)	First blossom date	Condition: Growth of plants	Condition: Color of leaves
15-16	3,200	High[t]	High	7.5		Poor	Light green
8-9	"	"	"	6.5		"	Dark green
15-16	8,000	Low[y]	Low	15.5	Aug. 12	Plenty of leaves	Yellow green
8-9	"	"	"	14.0	Aug. 6	Few leaves but plenty of flowers	Green

* Midday with clear sky
t Soil kept moist
y To keep plants from wilting

period as shown in table 2, it will be noted that the growth responses of the plants showed more variation. Plants exposed to low light intensity for a long photoperiod were weak and short, while plants given the same low light intensity treatment with a shorter photoperiod grew even less. Plants exposed to high light intensity and subjected to a short photoperiod flowered on August 6, having few leaves and plenty of flowers while plants given the same light intensity but exposed to a long photoperiod flowered 6 days later, having plenty of leaves and the best elongated stems of all groups. The slightly later flowering of this particular group as compared to the earlier flowering of plants subjected to short-day and high light influences may be attributed to the difference in the length of the photoperiod, since both groups grew in poor soil with minimum moisture.

Experiments with Soybeans

A series of similar experiments was conducted with Biloxi soybeans. The treatments given the beans grown in flats and pots were identical to those given the Cosmos plants.

The soybeans grown in flats watered with liquid manure, showed distinct variation in growth and flowering responses as may be seen in table 3. The group of plants given a 15-16 hour photoperiod with low light intensity developed many branches and elongated in height to 45 inches, while the group

Table 3. Observation on the Growth of Soybeans

(All plants in flats watered with liquid manure)
(Seed planted June 28; final records Aug. 1935)

Day length (hours)	Light intensity f.c.*	Soil: Moisture	Soil: Fertility	Ave. height (inches)	First blossom date	Leaf starch test	Condition: Growth of plants	Condition: Color of leaves
15-16	3,200	High[t]	Low	45.0		Positive	Very branching	Light green
8-9	8,000	"	"	23.0	Aug. 4	"	Coarse growth	Yellow green
15-16	"	"	"	32.0		"	Elongated growth	Green

* Midday with clear sky
t Soil kept moist

receiving the same length of photoperiod with high light intensity elongated in height to only 32 inches with no branching. The other group of plants subjected to an8-9 hour photoperiod with high light intensity, grew to be coarse in leaf and stem development, attained a height of 23 inches and flowered after 37 days of growth. The great height attained by the long-day plants is attributed to the influence of the low light intensity while the flowering of the plants subjected to high light intensity might be attributed to the short photoperiod.

Soybeans grown in pots and given different treatments of soil moisture and fertility, light intensity and photoperiod showed additional variation as may be seen in table 4. Those plants given a 15-16 hour photoperiod at low light intensity, growing in rich soil and receiving high moisture, developed to 54 inches in height. This group had leaves much larger and thinner than the leaves of any of the other groups. The low light intensity and higher humidity probably account for this morphological leaf change. The plant internodes were much longer than any of the other groups. Plants receiving a long photoperiod of high light intensity, growing in poor soil and receiving low moisture, developed the second highest growth of 29 inches. The leaves of this group were second largest in size, however, the plant stems of this group were the largest of all groups. Plants given an8-9 hour photoperiod of high light intensity, growing in poor soil and receiving

Table 4. Observations on the Growth of Soybeans

(All plants in 8 inch pots - seed planted June 28; final records August 22, 1935)

Day length (hours)	Light intensity f.c.*	Soil		Average Height (inches)	First blossom date	Leaf size (inches)	Condition	
		Moisture	Fertility				Growth of plants	Color of leaves
15-16	3,200	High[t]	High	54.0		6.0x4.0	Internodes long	Light green
8-9	"	"	"	20.0	Aug. 6	3.0x2.0	Slow lateral growth	Dark green
15-16	8,000	Low[y]	Low	29.0		5.0x3.5	Large stems	Yellow green
8-9	"	"	"	20.0	July 29	3.25x2.75	Branched with lateral growth	Green

* Midday with clear sky
t Soil kept moist
y To keep plants from wilting

low moisture, flowered in 31 days. These plants were small in leaves and stems. Plants exposed to an 8-9 hour photoperiod of low light intensity, growing in rich soil and receiving high moisture, grew to the same height as the short-day, high-light plants but flowered 8 days later. This group of plants had very little lateral growth. Its leaves were the smallest of all the groups. In regard to all the groups it seems that the large leaf development is associated with long photoperiods, however, low light intensity seemed to have augmented the size of leaf even more. Height of groups may be looked at in the same regard. As to the differences in the flowering dates of groups mentioned only plants on short photoperiods flowered, and flowering was retarded 8 days, but not prevented by the low light intensity.

In 1938 the experiment with the Biloxi Soybeans was repeated, using the same treatments and procedure as in the experiments of 1935. Salvia was substituted for Cosmos. The flat grown groups were omitted and only pot grown plants were observed. The observations on the bean experiments grown in 1935 were confirmed by the experiments of 1938, as is shown in table 5. Long-day, low-light plants grew vine-like and developed the largest and thinnest leaves of all groups. These plants elongated to a height of 34 inches to be the tallest of all the groups. Long-day, high-light plants developed a coarse type of growth with the lower leaves mostly dying, and those

Table 5. Observations on the Growth of Soybeans

(All plants in 8 inch pots - seed planted April 28; final record June 4, 1938)

Day length (hours)	Light intensity f.c.*	Soil		Average Height (inches)	First blossom date	Leaf size (inches)	Condition	
		Moisture	Fertility				Growth of plants	Color of leaves
15-16	3,200	High[t]	High	34.0		6.0x4.0	Vining	Light green
8-9	"	"	"	20.0	Buds about to open	2.5x3.5	Small stems	Dark green
15-16	8,000	Low[y]	Low	28.0	Buds not large	3.5x2.5	Coarse; lower leaves shed	Yellow green
8-9	"	"	"	21.0	May 25	3.5x2.5	Stems medium	Green

* Midday with clear sky
t Soil kept moist
y To keep plants from wilting

leaves that matured and remained on the plant were the second largest in size and measured about 3½ x 2½ inches. These plants developed very small buds during a limited growth period which were not identified as flower buds. This group attained 28 inches in height to be the second tallest. Plants exposed to short days of high light intensity grew 21 inches tall and flowered 32 days after planting of seed. The stems were medium as compared to the other groups. The other group of plants given a short photoperiod of low light intensity developed the smallest and weakest plants in every respect. At the time of harvesting (June 4) the plants of this particular group had buds about to open. In regard to these groups, it seems that plants subjected to short photoperiods were induced to flower regardless of the degree of light intensity, amount of moisture or fertility of the soil; however, the influence of high light seems to have forced flowering. Plants subjected to long photoperiods regardless of light intensity, moisture and fertility were much taller and larger. Plants of these long photoperiod groups were influenced to grow vine-like by low light intensity, while high light caused a coarse development. Large leaves are also associated with long photoperiods, particularly when shaded.

Table 6. Observations on the Growth of Salvia

(All plants in 8 inch pots - seed planted April 28; final records June 4, 1938)

Day length (hours)	Light intensity f.c.*	Soil Moisture	Soil Fertility	Average height (inches)	First blossom date	Leaf size (inches)	Condition: Growth of plants	Condition: Color of leaves
15-16	3,200	High[t]	High	10.0	-	2.5x3.0	Large stems; Small leaves in lower axils, buds higher up	Light green
8-9	"	"	"	4.0	-	1.0x0.75	Budding very slow	Dark green
15-16	8,000	Low[y]	Low	5.0	-	1.25x1.0	Leaves in lower axils; small buds higher up	Yellow green
8-9	"	"	"	3.0	-	1.0x1.5	Smallest stems; buds and small leaflets in axils of all leaves	Green

* Midday with clear sky
t Soil very moist
y To keep plants from wilting

Experiments with Salvia

These experiments were conducted in the same manner as those with Cosmos and Biloxi soybeans grown in pots. Observations were made with the same point of view of noticing the general growth of all the groups as to their height, size of leaf, branching, first blossom date and color of leaves during a limited growth period as shown in table 6. Plants grown in rich soil, receiving plenty of moisture and subjected to long photoperiods with low light intensity, developed stems 10 inches long, being the tallest of all the groups. These plants had the largest leaves measuring 2½ x 3 inches. Other general characteristics observed were that the group had large stems, small leaves in the lower leaf axils and buds in leaf axils higher up on the plant stem. Plants given an 8-9 hour photoperiod with low light intensity grown in soil with plenty of moisture developed small plants 4 inches tall with leaves 1 x 3/4 inches large. These plants produced buds very slowly. Plants exposed to a 15-16 hour photoperiod with high light intensity grown in poor soil with a minimum moisture, elongated to 5 inches in height. This group had leaves measuring 1½ x 1 inches. There were branches in the lower leaf axils and small vegetative buds in leaf axils higher up the plant stem. Plants subjected to an 8-9 hour photoperiod with high light intensity grown in poor soil with a minimum amount of moisture elongated to 3 inches, the least in height of all the Salvia groups.

The leaves measured 1 x 1½ inches. The stems were the smallest. There were buds and small leaflets in the axils of all leaves. This last fact indicates probable early flowering. In regard to all the leaf sizes of the various groups, it seems that the plant subjected to long photoperiods and grown in rich or poor soil developed the largest leaves. The leaves of plants grown in rich soil were considerably larger than those grown in poor soil.

Harvesting Data

In the harvesting of all material the plants grown in one flat were treated as a group. All tops were gathered for the green weight, being handled as rapidly as possible in order to avoid enzymatic changes in the material, and then placed in an oven for 30 minutes at 100 degrees C. This material was then dried at 70 degrees C. for 24 hours to constant weight. All other plant parts were given this same treatment after harvesting. Following this period of dehydration the plant parts were weighed and sealed in separate desiccators for future use. The same treatment was used for obtaining green and dry weights of stems, leaves, roots and nodules of plants grown in pots.

Harvesting data, Cosmos plant material

Harvesting data of Cosmos plants grown in flats and

Table 7. Harvesting data; Cosmos Grown in Flats - 1935

Growth conditions	No. of plant	Average height of plants (inches)	Buds	Flowers	Plant weight (gr.) Green Tops	Green roots	Green Total	Green Average	Dry Tops	Dry roots	Dry Total	Dry Average
High moisture Low light Long day	59	16.0	None	None	None	47.25	4.12	0.87	5.50	0.91	6.41	0.187
High moisture High light Short day	40	10.5	27	4	15	23.25	3.72	0.674	3.50	1.25	4.75	0.118
High moisture High light Long day	75	12.0	3	None	None	135.83	27.55	2.19	20.39	8.60	28.99	0.380

watered with liquid manure revealed some interesting facts in regard to final height at time of harvest, number of buds, flowers, fruit, green weights of tops and roots, average dry weights of tops and roots, average green and dry weights of all plants, and the average individual green and dry weights for plants of all groups, as shown in table 7. Those plants subjected to low light intensity for a long photoperiod attained the greatest height, produced no buds, flowers or fruit, and had an average green weight per plant of 0.67 grams which dried out to 0.187 grams. Plants exposed to high light, long day conditions attained 12 inches in height, produced 3 buds, no flowers or fruit, and had an average weight per plant of 2.19 grams green and 0.38 grams dry. Plants given a high light and short day treatment remained the shortest of all groups but developed 27 buds, 4 flowers and 15 fruit and had an average green weight of 0.674 grams which dried out to 0.118 grams. In regard to the accumulation of dry matter, it seems that the plants subjected to long photoperiods regardless of light intensity were most productive; however, the higher light intensity caused an upward trend in dry matter produced.

Cosmos plants grown in pots gave the data shown in table 8. Plants given long days of high light intensity and grown in poor soil of low moisture grew to be the tallest of all plants. They attained an average height of 17.8 inches.

Table 8. Harvesting Data. Cosmos Grown in Pots - 1935.

Growth conditions	Pot number	No. of plants	Average height of plants (in.)	Buds	Flowers	Fruit	Plant weight (gms) Green Tops	Green Roots	Green Total	Green Average	Dry Tops	Dry Roots	Dry Total	Dry Average
	1	2.0	11.00	None	None	None	4.69	0.49	5.18		0.74	0.19	0.93	
	2	2.0	8.50	"	"	"	6.44	0.37	6.81		0.90	0.21	1.11	
High moisture	3	8.0	10.00	"	"	"	16.37	1.50	17.87		1.50	0.38	1.88	
Fertile soil	4	10.0	8.00	"	"	"	9.71	0.75	10.46		1.09	0.20	1.29	
Long day	5	2.0	7.00	"	"	"	1.70	0.25	1.95		0.50	0.10	0.60	
Low light	6	1.0	8.00	"	"	"	1.00	0.12	1.12		0.30	0.05	0.35	
	7	Died	--	-	-	-	--	--	--		--	--	--	
	8	Died	--	-	-	-	--	--	--		--	--	--	
Average		4.1	8.75	0	0	0	6.65	0.58	7.23	1.763	0.84	0.19	1.03	0.251
	1	1.0	7.00	None	None	None			0.57				0.12	
	2	1.0	7.50	"	"	"			0.60				0.15	
High moisture	3	Died	--	-	-	-								
Fertile soil	4	Died	--	-	-	-								
Short day	5	Died	--	-	-	-								
Low light	6	Died	--	-	-	-								
	7	Died	--	-	-	-								
	8	Died	--	-	-	-								
Average		1.0	7.25	0	0	0			0.58	0.580			0.13	0.130
	1	8.0	14.00	1.0	None	None	27.98	6.31	34.29		4.96	1.99	6.95	
	2	15.0	16.50	None	"	"	31.38	6.71	38.09		5.00	2.27	7.27	
Low moisture	3	12.0	14.00	"	"	"	35.75	9.78	45.53		6.18	3.03	9.21	
Poor soil	4	6.0	13.00	"	"	"	30.85	8.28	39.19		4.83	2.60	7.43	
Long day	5	11.0	18.00	4.0	1.0	1.0	22.65	6.70	29.35		3.38	2.09	5.47	
High light	6	10.0	16.00	None	None	None	25.20	7.93	33.13		3.98	2.35	6.33	
	7	14.0	13.50	4.0	1.0	"	35.90	3.45	39.35		3.39	0.86	4.25	
	8	10.0	18.00	2.0	1.0	"	46.43	14.80	61.23		6.39	6.81	13.20	
Average		10.7	17.80	1.3	0.3	0.12	32.02	8.00	40.02	3.74	4.76	2.75	7.51	0.701
	1	14.0	19.00	9.00	5.00	10.00	28.30	2.63	30.93		3.89	0.74	4.63	
	2	8.0	16.00	6.00	4.00	6.00	20.56	2.42	22.98		2.56	0.61	3.17	
Low moisture	3	6.0	14.00	5.00	2.00	7.00	12.20	1.35	13.55		1.45	0.47	1.92	
Poor soil	4	14.0	13.00	14.00	2.00	8.00	22.70	2.99	25.69		2.59	0.71	3.30	
Short day	5	8.0	15.50	15.00	1.00	3.00	16.92	2.25	19.17		2.04	0.65	2.69	
High light	6	4.0	20.00	10.00	None	5.00	11.50	1.67	13.17		1.42	0.55	1.97	
	7	8.0	16.50	11.00	1.00	6.00	22.00	3.80	25.80		2.80	0.92	3.72	
	8	13.0	16.00	12.00	5.00	2.00	28.25	3.35	31.60		2.93	0.87	3.80	
Average		9.3	16.25	10.25	2.50	5.87	20.31	2.55	22.86	2.45	2.46	0.69	3.15	0.337

These plants developed few buds, flowers and fruit. They had an average green weight of 3.74 grams which dried out to 0.701 grams. Plants given short days with high light intensity and grown in poor soil with little moisture grew second in height to 16.25 inches. These particular plants had an abundance of buds, flowers and fruit as compared to the other groups. This group had an individual green weight of 2.45 grams which dried out to 0.337 grams. Plants subjected to long days with low light intensity and grown in fertile soil with high moisture developed to only 8.75 inches in height, just one inch more than plants given the short day, low light intensity treatment. Long-day, low-light plants produced no buds, flowers or fruit, as was the case of the short day, low light intensity treated plants; however, long day, low light intensity treated plants had an individual green weight of 1.76 grams which dehydrated to 0.251 grams while the short-day, low-light-intensity plants mostly died with only 2 pots remaining with one plant each averaging 0.58 grams in green weight and 0.13 grams dry weight. In considering the growth of all these groups, plants of long day, high light intensity treatment grown in poor soil with low moisture, accumulated the greatest amount of dry matter, which may be accounted for by the favored position of the group for maximum photosynthesis. The short-day, high-light-intensity plants failed to produce as much dry matter as the high-light, long-day plants but did produce more buds, flowers and fruit which was probably due to the short photoperiod. The other groups as shown in table 8 seemed to be inhibited in dry matter accumulation because of a lack of light intensity, or an increased humidity caused by the cheesecloth inclosure.

Harvesting data, Biloxi soybean material

Biloxi soybeans grown in flats and watered with liquid manure produced nearly the same results as Cosmos but differed somewhat in regard to the green weight, and dry weight, of plant materials as shown in tables 7 and 9. This difference is particularly noted in the average individual plant weights and was due, in part at least, to differences in stand.

Soybeans grown in pots produced the harvest data shown in tables 10, 11, and 12. Plants exposed to long days with low light intensity grew to an average height of 63.87 inches at the time of harvest as shown in table 10. They produced no buds, flowers or fruit but had an average green weight of 41.85 grams and an average dry weight of 10.62 grams as shown in tables 11 and 12. Only one plant in this group had any nodules. Plants given the short day, low light intensity treatment produced plenty of buds, flowers and fruit but were later than plants given the short day, high light treatment. A slow rate of photosynthesis in the short-day, low-light plants probably accounts for this delayed bud formation,

Table 9. Harvesting Data: Soybeans Grown in Flats-1935
(All plants watered with liquid manure)

Growth conditions	No. of plants	Average height of plants (in.)	Buds	Flowers	Fruit
High moisture Low light Long day	13	52	None	None	None
High moisture High light Short day	7	24	"	4	19
High moisture High light Long day	35	34	"	None	None

Green weight (gms.)

Growth condition	Leaves	Fruit	Stems	Roots	Nodules	Total	Average
High moisture Low light Long day	34.49	None	47.89	54.55	None	136.93	10.53
High moisture High light Short day	10.54	10.15	13.79	19.23	"	53.71	7.67
High moisture High light Long day	49.15	None	64.38	69.89	1.89	185.31	5.29

Dry weight (gms.)

Growth condition	Leaves	Fruit	Stems	Roots	Nodules	Total	Average
High moisture Low light Long day	7.89	None	12.00	22.40	None	42.29	3.25
High moisture High light Short day	2.95	3.00	3.68	6.79	"	16.42	2.34
High moisture High light Long day	12.35	None	15.78	18.54	0.59	47.26	1.35

flowering and fruiting. The average weight per plant for short-day, low-light plants was 11.02 grams for green weight and 3.42 grams for dry weight. This group failed to develop any nodules on its roots. The general failure of nodule formation on the roots of the plants exposed to low light intensities probably may be accounted for by the low sugar content of the roots of plants grown in a moist, rich soil with a reduced rate of photosynthesis. Fred and his coworkers (2, 3) have emphasized the stimulating effect of carbohydrate synthesis on nitrogen fixation; and the conclusion may be reached that any factor, e.g., light intensity or day length, that will increase the carbohydrate level in the plant will tend to increase nodule formation and nitrogen fixation. Conversely, any method which decreases the carbohydrate concentration, such as short exposure to light and addition of combined nitrogen to the substrate, will lower nodule production and total nitrogen fixed.

Plants exposed to long day, high light intensity had elongated stems to a height of 36.75 inches. There were no buds, flowers or fruit formed; however, with this group, there was the greatest nodule formation as shown in tables 11 and 12. These plants averaged 38.69 grams green weight and 12.62 grams dry weight per plant. The increased nodule formation in this group may have been due to higher sugar content of plants grown in poor, low-moisture soil (3). Plants given short day, high light intensity treatment had fruit only at the time of

Table 10. Harvesting Data. Soybeans Grown in Pots - 1935.

Growth conditions	Pot	No. of plants	Av. height plants (in.)	Buds	Flowers	Fruit
	1	2	72.00	None	None	None
	2	2	20.00	"	"	"
High moisture	3	2	68.00	"	"	"
Fertile soil	4	2	69.50	"	"	"
Long day	5	1	71.00	"	"	"
Low light	6	2	70.00	"	"	"
	7	2	69.00	"	"	"
	8	2	71.50	"	"	"
Average		1.87	63.87	0	0	0
	1	1	23.50	6	4	11
	2	2	20.00	6	9	5
High moisture	3	2	20.50	7	8	12
Fertile soil	4	2	23.00	9	15	9
Short day	5	2	25.50	3	12	8
Low light	6	2	26.00	6	10	8
	7	1	22.00	4	3	5
	8	1	24.00	9	7	5
Average		1.625	23.06	6+	8+	8-
	1	2	32.00	None	None	None
	2	2	36.00	"	"	"
Low moisture	3	2	39.00	"	"	"
Poor soil	4	3	38.00	"	"	"
Long day	5	2	40.00	"	"	"
High light	6	2	36.00	"	"	"
	7	2	37.00	"	"	"
	8	2	36.00	"	"	"
Average		2.125	36.75	0	0	0
	1	2	18.00	None	None	20
	2	2	17.00	"	"	22
Low moisture	3	3	14.00	"	"	22
Poor soil	4	3	17.00	"	"	27
Short day	5	2	20.00	"	"	26
High light	6	2	14.00	"	"	16
	7	2	17.50	"	"	21
	8	3	15.70	"	"	32
Average		2.375	16.65	0	0	23+

Table 11. Green Weight in Grams of Soybeans Grown in Pots - 1935.

Growth conditions	Pot	Leaves	Fruit	Stems	Roots	Nodules	Total	Average plant wt.
	1	27.65	None	28.58	18.00	0.60	74.83	
	2	26.85	"	28.05	22.88	None	77.78	
High moisture	3	19.60	"	21.15	6.35	"	47.10	
Fertile soil	4	46.10	"	44.95	36.45	"	127.50	
Long day	5	28.07	"	24.72	18.16	"	70.95	
Low light	6	29.50	"	23.28	10.80	"	63.58	
	7	27.63	"	27.50	16.60	"	71.73	
	8	39.80	"	35.10	17.80	"	92.70	
Average		30.65	0	29.16	18.38	0.07	78.26	41.85
	1	9.30	6.38	4.91	1.65	None	22.24	
	2	6.80	2.45	3.98	1.29	"	14.52	
High moisture	3	9.56	4.63	5.82	1.80	"	21.81	
Fertile soil	4	10.03	4.64	5.00	1.80	"	21.47	
Short day	5	12.05	6.20	6.80	2.28	"	27.33	
Low light	6	7.97	3.91	4.59	1.81	"	18.28	
	7	5.70	2.90	2.68	1.11	"	12.39	
	8	5.30	2.56	3.98	1.65	"	13.49	
Average		8.33	4.20	4.72	1.67	0	18.92	11.02
	1	24.99	None	26.55	31.21	1.49	84.24	
	2	20.80	"	23.80	27.80	2.95	75.35	
Low moisture	3	31.50	"	28.11	28.41	2.27	90.29	
Poor soil	4	24.45	"	29.34	29.65	2.20	85.64	
Long day	5	26.15	"	21.46	25.05	1.61	74.26	
High light	6	30.27	"	28.00	25.45	4.43	88.15	
	7	32.14	"	31.30	31.77	0.59	95.80	
	8	24.08	"	20.22	18.53	1.42	64.25	38.69
		26.79	0	26.09	27.23	2.12	82.23	
	1	13.20	15.55	13.75	3.40	2.10	48.00	
	2	20.65	15.25	13.75	11.00	0.40	61.05	
Low moisture	3	16.15	12.70	9.53	8.85	None	47.23	
Poor soil	4	20.40	16.70	15.20	6.99	3.70	62.99	
Short day	5	15.50	13.70	11.85	4.60	3.90	49.55	
High light	6	12.80	8.70	7.32	7.95	None	36.77	
	7	18.10	15.65	14.05	7.91	2.05	47.76	
	8	9.60	16.55	12.30	9.48	1.99	49.92	
Average		15.80	14.35	12.22	7.52	1.76	51.65	21.74

Table 12. *Dry Weight in Grams of Soybeans Grown in Pots - 1935.*

Growth conditions	Pot	Leaves	Fruit	Stems	Roots	Nodules	Total	Average plant wt.
	1	6.80	None	6.30	7.60	0.42	21.12	
	2	6.17	"	6.39	9.89	None	22.45	
High moisture	3	4.90	"	4.62	2.88	"	12.40	
Fertile soil	4	10.19	"	9.36	14.30	"	33.85	
Long day	5	5.72	"	4.90	5.89	"	16.51	
Low light	6	5.75	"	4.55	3.67	"	13.97	
	7	6.72	"	6.69	6.79	"	20.20	
	8	6.41	"	6.70	6.10	"	19.21	
Average		6.58	0	6.19	7.14	0.05	19.96	10.65
	1	2.38	1.59	2.10	0.63	None	6.70	
	2	1.81	0.80	1.17	0.64	"	4.42	
High moisture	3	2.18	2.23	1.45	0.77	"	6.63	
Fertile soil	4	2.46	1.40	1.57	0.77	"	6.20	
Short day	5	3.05	1.90	2.01	0.85	"	7.81	
Low light	6	1.94	0.89	1.28	0.84	"	4.95	
	7	1.54	0.85	0.85	0.59	"	3.83	
	8	1.46	0.69	1.15	0.76	"	4.06	
Average		2.10	1.29	1.45	0.72	0	5.56	3.42
	1	6.98	None	7.22	10.42	0.43	25.05	
	2	6.18	"	6.60	10.25	0.99	24.02	
Low moisture	3	10.00	"	8.05	11.80	0.77	30.62	
Poor soil	4	7.48	"	8.45	10.95	0.81	27.69	
Long day	5	7.35	"	5.68	9.15	0.55	22.83	
High light	6	9.68	"	8.05	10.39	1.60	29.72	
	7	10.56	"	9.13	12.99	0.20	32.88	
	8	6.78	"	5.31	10.40	0.37	22.86	
Average		8.13	0	7.20	10.79	0.71	26.83	12.62
	1	5.45	3.88	3.80	1.50	0.91	15.54	
	2	6.10	3.58	3.90	2.67	0.18	16.43	
Low moisture	3	4.48	2.95	2.68	2.10	None	12.21	
Poor soil	4	6.30	4.12	4.48	2.89	1.28	19.07	
Short day	5	4.83	3.48	3.42	1.90	1.28	14.91	
High light	6	3.50	1.82	2.10	2.10	None	9.52	
	7	5.55	4.05	4.10	3.18	0.60	17.48	
	8	2.69	3.82	3.40	3.20	0.67	13.78	
Average		4.86	3.42	3.48	2.44	0.61	14.81	6.23

harvest which showed that the flowering stage had been passed. This group had an abundance of root nodules which at the time of harvest did not weigh quite as much as the nodules of the long-day, high-light plants, indicating probably that foods had been translocated to the newly formed fruit. These short-day, high-light plants had a green weight of 21.74 grams and a dry weight of 6.23 grams per plant.

Soybeans grown in pots in 1938 and subjected to similar growth conditions as the beans grown in pots in 1935 reveal some contradicting results in regard to average plant weights, but the experiments of different years otherwise agree in harvesting data. Biloxi soybeans grown in pots in 1938 were harvested after 43 days of growth. The green weight of various plant parts is shown in table 13. Plants exposed to long day, and high light intensity developed the greatest average green weight of 26.180 grams, and this group had more root nodule development than any other group. Long-day, low-light plants averaged next in green weight at 18.438 grams, 1.269 grams more than the average green weight of plants given the short-day, high-light treatment. These short-day, high-light plants were the only other group to have nodules. Plants grown in moist fertile soil with low light and long or short photoperiods produced no nodules. The short-day, low-light plants grown in moist fertile soil developed the least green weight per plant, 8.164 grams.

Table 13. Harvesting Data. Green Weight in Grams of Soybeans Grown in pots - 1938.

Growth conditions	Pot	No. of plants	Leaves	Stems	Roots	Nodules	Total	Average plant wt.
	1	5	34.40	42.30	12.45	None	89.05	
	2	"	36.60	39.30	11.34	"	87.24	
High moisture	3	"	42.60	49.00	19.57	"	111.17	
Fertile soil	4	"	36.20	40.70	10.18	"	87.08	
Long day	5	"	29.80	33.70	8.08	"	71.58	
Low light	6	"	44.30	47.40	11.13	"	102.83	
	7	"	46.40	48.70	9.25	"	104.35	
	8	"	37.00	41.40	5.89	"	84.29	
Average		5	38.40	42.81	10.98	0	92.19	18.438
	1	5	20.30	16.20	4.39	None	40.89	
	2	5	16.30	13.30	2.15	"	31.75	
High moisture	3	3	12.00	9.70	4.73	"	26.43	
Fertile soil	4	4	24.30	19.10	4.38	"	47.78	
Short day	5	4	15.80	12.40	4.16	"	32.36	
Low light	6	5	16.60	14.20	2.47	"	33.27	
	7	4	16.80	13.90	3.34	"	34.04	
	8	4	14.10	12.60	4.52	"	31.22	
Average		4.25	17.02	13.92	3.76	0	34.70	8.164
	1	4	37.70	43.80	44.28	0.220	126.000	
	2	"	29.70	36.90	32.82	0.175	99.595	
Low moisture	3	"	27.60	35.60	36.49	0.610	100.300	
Poor soil	4	"	34.10	43.10	30.47	0.230	107.900	
Long day	5	"	32.90	40.70	31.51	0.485	105.595	
High light	6	"	36.70	45.50	31.20	0.000	113.400	
	7	"	29.30	36.70	28.36	0.740	95.100	
	8	"	28.60	36.30	24.52	0.580	90.000	
Average		4	32.07	39.82	32.45	0.380	104.720	26.180
	1	4	27.60	23.40	21.60	0.00	72.60	
	2	"	31.60	26.30	25.90	0.00	83.80	
Low moisture	3	"	22.70	20.70	16.76	1.24	61.40	
Poor soil	4	"	18.60	17.20	17.28	0.92	54.00	
Short day	5	"	28.20	25.30	24.44	0.66	78.60	
High light	6	"	24.40	19.60	20.02	1.88	65.90	
	7	"	28.40	22.30	24.98	0.42	76.10	
	8	5	29.70	25.20	18.16	0.54	73.60	
Average		4.12	26.40	22.50	21.14	0.70	70.74	17.169

Chemical Analyses

After considering the observable effects caused by the various growth conditions upon the plants, an attempt was made to see what might be revealed biochemically. In the summer of 1935 a study made with plants growing under the various conditions of light intensity, length of photoperiod, soil moisture and fertility, revealed the following biochemical facts:

Experiments with Cosmos

Cosmos grown in pots developed slowly, producing only a small amount of plant material for chemical analysis. Only two groups afforded sufficient plant material for the analysis. High-light, short-day plants grown in poor soil low in moisture did not produce the total carbohydrates or total nitrogen that high-light, long-day plants grown under similar conditions produced, as shown in table 14. The high-light, long-day plants contained more carbohydrates and nitrogen generally than the high-light, short-day plants. This difference in carbon and nitrogen levels of the two groups may be assigned to differences in total photosynthesis.

Experiments with soybeans

Biloxi soybeans grown in flats, watered with liquid manure and given various treatments of light intensity and photoperiods produced the data shown in table 15. High-light, short-day plants developed the greatest level of total carbohydrates and nitrogen accumulation of all groups. High-light, long-day plants developed a relatively high carbohydrate accompanied by a low nitrogen accumulation. High-light, short-day plants differed considerably from the high-light, long-day plants in having 147 per cent more soluble nitrogen and 26 per cent more residual nitrogen. It is generally assumed that factors that decrease the carbohydrate level in plants should increase the soluble nitrogen level. Low-light, long-day plants, although having the greatest dry weight per single plant for all the groups grown in flats, developed the lowest carbohydrate level of all groups, and a relatively high nitrogen level when compared to the high-light, long-day group. From this consideration, it might be assumed that low-light, long-day treatment is suitable for slow accumulation of carbohydrates and nitrogen; high-light, short-day treatment is suitable for a faster accumulation of carbohydrates and nitrogen and that high-light, long-day treatment increases the carbohydrate level while nitrogen accumulation lags.

A chemical analysis was made of Biloxi soybean stems and leaves combined. Table 16 reveals the data. The growth of these plants gave interesting results. Plants exposed to high-light, long-day and grown in a poor soil of low moisture developed a very high carbohydrate level and showed

Table 14. Chemical Composition of Cosmos Grown in Pots - 1935.

Growth conditions	Carbohydrates			Nitrogen	
	Reducing sugars	Sucrose	Total	Soluble	Residual
Poor soil Low moisture High light Short day	156.50*	15.70	172.20	44.90	52.38
Poor soil Low moisture High light Long day	184.75	50.35	235.10	48.20	82.57

* Mg. of substance per 100 gr. of original green plant material

Table 15. Chemical Composition of Soybeans Grown in Flats-1935.
(Leaves and stems combined)
(All plants in flats watered with liquid manure)

Growth conditions	Carbohydrates			Nitrogen	
	Reducing sugars	Sucrose	Total	Soluble	Residual
High moisture Low light Long day	150.00*	138.00	288.00	85.20	101.31
High moisture High light Short day	219.00	174.65	393.65	107.71	114.60
High moisture High light Long day	222.35	160.50	382.85	43.89	90.70

*Mg. of substance per 100 gr. of original green plant material

the highest residual nitrogen content when compared to the other groups. High-light, short-day plants revealed a relatively high carbohydrate level but a low nitrogen level when compared to plants grown in fertile soil. Low-light, long-day plants grown in very moist fertile soil developed the lowest carbohydrate level but an intermediate nitrogen level when considered with all the groups. Low-light, short-day plants grown in a very moist fertile soil developed a higher carbohydrate level than low-light, long-day plants but a lower carbohydrate level than high-light, long-day and high-light, short-day plants. However, low-light, short-day plants showed more soluble nitrogen present than all the other single groups.

Chemical analyses of Biloxi soybeans grown in 1938 with the same treatments as those of the experiments conducted in 1935 are shown in table 17 on the chemical composition of leaves and table 18 on the chemical composition of stems. In regard to the influences of light intensity and photoperiod on the chemical content of plant material grown in different fertility and moisture of soil, the leaves of the short-day groups had low reducing sugars, but relatively high levels of total carbohydrates and residual nitrogen. The long-day groups developed fairly high reducing sugars and sucrose; however, there was more variation of content shown in the high-light, long-day group. In regard to the nitrogen content of all the

Table 16. Chemical Composition of Soybeans Grown in Pots-1935.
(Stems and leaves combined)

Growth conditions	Carbohydrates: Reducing sugars	Carbohydrates: Sucrose	Carbohydrates: Total	Nitrogen: Soluble	Nitrogen: Residual
High moisture Fertile soil Long day Low light	105.00*	41.30	146.30	50.20	91.29
High moisture Fertile soil Short day Low light	150.50	109.25	159.75	122.00	51.52
Low moisture Poor soil Long day High light	328.50	106.60	435.10		121.13
Low moisture Poor soil Short day High light	270.25	95.25	365.50	29.40	110.00

*Mg. of substance per 100 gr. of original green plant material

groups, low light and high soil fertility caused an accumulation of soluble as well as residual nitrogen.

The chemical composition of stems of Biloxi soybeans grown in pots in 1938 is shown in table 18. Stems of long-day groups grown in soils of different fertility and moisture indicated a high total carbohydrate content; however, there was a wide difference in their reducing sugar percentages. Short-day groups showed very low reducing sugar contents. As to the nitrogen content of all the groups, they showed a relative even amounts of residual nitrogen, but the low light groups with their fertilized soil showed the highest soluble nitrogen content.

Table 17. Chemical Composition of Leaves of Soybeans Grown in Pots - 1938.

Growth conditions	Carbohydrates			Nitrogen	
	Reducing sugars	Sucrose	Total	Soluble	Residual
High moisture Fertile soil Long day Low light	89.91*	87.63	177.54	173.32	735.90
High moisture Fertile soil Short day Low light	9.89	188.01	197.90	206.13	545.79
Low moisture Poor soil Long day High light	234.77	162.86	397.63	94.14	621.78
Low moisture Poor soil Short day High light	59.52	172.81	232.33	121.93	560.70

*Mg. of substance per 100 gr. of original green plant material

Table 18. Chemical Composition of Stems of Soybeans Grown in Pots - 1938.

Growth conditions	Carbohydrates			Nitrogen	
	Reducing sugars	Sucrose	Total	Soluble	Residual
High moisture Fertile soil Long day Low light	66.60	167.67	234.27	276.05	120.38
High moisture Fertile soil Short day Low light	24.98	104.40	129.38	315.60	121.85
Low moisture Poor soil Long day High light	167.75	190.99	358.74	181.47	102.79
Low moisture Poor soil Short day High light	9.73	185.39	195.12	173.23	120.51

*Mg. of substance per 100 gr. of original green plant material

DISCUSSION OF RESULTS

The experiments conducted in the summer of 1935 gave results in agreement with those reported by Garner and Allard (4). Short-day plants were forced into flowering by removing the plants to a ventilated dark chamber in the afternoon and returning them to the greenhouse in the morning for an 8-9 hour light exposure. The 1938 experiments also were in agreement. Biloxi soybeans were strictly short day in response and were not forced into flower by attempts to increase the carbohydrate level in the plants by growing them at low water levels on infertile soil. Cosmos, however, were forced into flowering with long days by stunting treatments and prevented from flowering on short days by reducing the light and increasing the soil fertility and moisture (Table 2). Soybeans were not prevented from flowering by shading, and chemical analyses (Table 17) indicated a high sucrose content in the leaves of these plants.

Plant groups subjected to long photoperiods of low light intensity developed light green colored leaves, while plants subjected to long photoperiods of high light intensity developed yellowish green colored leaves. Plants given short photoperiods with high light intensity developed an ordinary green color of leaves, while plants given a similar photoperiod with low light intensity developed the darkest green leaves of all plant groups, indicating that the deep green of chlorophyl in plant leaves may be a partial compensation for the reduced light intensity. Reducing the light intensity, however, normally brought about a lower dry weight and sugar level. Plants given high light intensity regardless of the photoperiod had higher sugar levels than plants exposed to low light intensities irrespective of the photoperiodic length.

High soluble nitrogen content was generally evident in plants growing under the influence of low light. It will be recalled that these plants also were heavily watered and were fertilized with ammonium sulfate. When a nitrogen salt was added to the substrate of legume plants, there was little evidence of nodule formation. An increased light intensity on plants grown in a soil low in fertility helped nodulation, presumably because of the raised level of carbohydrates. Nodulation was increased still further by a longer photoperiod. A difference in the photoperiod and light intensity caused a variation in the carbon and nitrogen levels in the plant tissues. Klebs (11) arrived at the conclusion that a piling up of carbohydrate food products favored flower production. The work of Kraus and Kraybill (12) indicates that the relationship of carbohydrates to nitrogen is closely associated with the vegetative and reproductive growth of plants. Hendricks and Harvey (10) found an increased concentration of carbohydrates in the leaves of Easter lilies grown under artificial light to be correlated with early flowering. In our experiments we found that plants subjected to an abundance of moisture and mineral nutrients and exposed to long photoperiods at low light intensity failed in the accumulation of the carbohydrate level above the nitrogen level. Plants grown under such conditions were vine-like and non-flowering. Biloxi soybean plants given high moisture and an abundance of available nutrients, but exposed to short photoperiods at low light intensity built up a higher carbohydrate level, and initiated early flowering. It is significant, and characteristic of the photoperiodic response, that plants exposed to light for only half of the normal day should have accumulated higher percentages of carbohydrate than the more rapidly growing plants exposed for the full day. Plants subjected to high light intensity for a long photoperiod and grown in a soil of low fertility developed a still higher carbohydrate level, but failed to flower. Plants exposed to high light intensity for a short photoperiod and grown in a soil low in fertility developed a high level of carbohydrates and flowered earlier than the short-day, shaded plants. Thus, in our experiments, it was found that an increased concentration of carbohydrates in plants failed to initiate early flowering in Biloxi soybeans grown with long days.

The results can be explained by assuming that some essential differentiation product is destroyed by light in short-day plants. Hamner (8, 9) has shown, for example, that a short exposure to light during the dark period will prevent flowering of Xanthium. Presumably a lower sugar level than was obtained in our plants would have checked flowering on short days because of the lack of this essential material for differentiation (14).

SUMMARY

Three short-day plants, Cosmos (*Cosmos bipinnatus*), Salvia (*Salvia splendens*), and Biloxi soybeans (*Glycine Max*), were grown with 14-16 hours of daylight (long day) or 8-9 hours (short day) under conditions favorable and unfavorable for differentiation and observed for flowering. Conditions favorable for differentiation were obtained by growing in a sand mixture with full greenhouse light and watering sparingly. Conditions unfavorable for differentiation were obtained by growing in fertilized compost with 40 per cent light and watering liberally.

Flowering of Cosmos and Biloxi soybeans was hastened by shortening a 14-16 hour day to 8-9 hours. Biloxi soybeans did not flower on the longer days. Long-day Cosmos grown under conditions favoring differentiation flowered 6 days after the short-day plants on August 12.

Reducing the light to 40 per cent of normal and simultaneously increasing watering and soil fertility caused a weak, twining growth in long-day soybeans and a short, weak growth in short-day beans. Flowering was prevented in Cosmos, but not in short-day soybeans.

Plants grown on long photoperiods were larger, but carbohydrate percentages, particularly of sucrose, were frequently

higher in short-day plants, even with reduced light and high soil fertility.

Soybean plants grown under conditions unfavorable to differentiation failed to produce nodules while nodulation was heavy under high-differentiation conditions.

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