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MORPHOLOGY AND REPRODUCTIVE DEVELOPMENT OF SOYBEANS UNDER ARTIFICIAL CONDITIONS*

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DOWNS R. J. and THOMAS J. F. *Morphology and reproductive development of soybeans under artificial conditions.* BIOTRONICS **19**, 19–32, 1990. Response of soybeans grown in controlled environments to variations in temperature, photoperiod, irradiance level and spectral quality was examined. Over the range of temperatures examined day/night temperatures of 26/22°C induced the most rapid development and a relatively compact plant habit. Simulated natural temperature programs and simulated natural progressions of daylengths did not significantly alter plant morphology when compared with growth under constant photoperiod conditions. The best selection for a suitable photoperiod duration was determined to be sunrise to sunset on May 1 at the latitude at which the variety is commonly grown. The use of incandescent lamps in the controlled-environment rooms for photoperiod control was the major cause for excessive internode elongation. Fluorescent lamps produced more compact plants than those exposed to incandescent lamps, and controlled reproduction adequately even in cultivars insensitive to red light.

Key words: *Glycine max* (L.) Merr.; temperature; photoperiod; light source; irradiance level.

INTRODUCTION

Soybeans and many other plant species grown in greenhouses and controlled-environment chambers often fail to resemble their counterparts in the field. Soybeans grown in the greenhouse under low light levels during winter, or exposed to high temperatures and a reduction in irradiance by thermal shading during summer, often have reduced leaf areas and elongated internodes. The excessively long internodes of soybeans grown in controlled-environment facilities (*24*), however, cannot be explained so readily, but must be related to programming of one or more of the environmental parameters.

Modern controlled-environment chambers provide all the conditions necessary for simulating the field phenotype (*21*). For instance, at ambient CO_2 levels the

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photosynthesis rate of soybeans is about the same over an illuminance range of 21.5 to 75.0 klx (*3*), therefore, light levels of 45 klx (photosynthetic photon flux density (PPFD) of 650 μmol m^{-2} s^{-1}) provided by the fluorescent and incandescent lamps found in many plant growth chambers should be sufficient for normal soybean growth and development. Changes in the spectral quality of the light, however, may induce marked changes in morphogenesis (*24*, *29*). Most plant growth chambers use fluorescent or metal halide lamps as the high-irradiance light source (*8*). The addition of incandescent lamps, based on reports that they promote more normal plant growth and increased plant dry weight (*12*, *13*, *17*, *20*, *32*) significantly alters the spectral quality of light in growth chambers (*7*). Such dry weight increments, however, are also frequently accompanied by increased stem height (*7*, *14*).

Incandescent lamps are the most common light source used for photoperiod control because they are easy to install, produce less shading of natural light and cause less strain on greenhouse structural members than the luminaires of other light sources. Incandescent lamps are also more effective for daylength extensions than fluorescent lamps (*2*, *9*) or high-intensity discharge lamps (*5*). With the exceptions of some soybean varieties (*4*, *16*) and long-day (LD) plants in which flowering is accompanied by elongation of a scape (*9*), flowering of many LD plants can be as equally well controlled by incandescent as by fluorescent light sources. The promotion of internode elongation by incandescent lamps, however, makes them undesirable for photoperiod control. Stem height of 'Agate' soybean, for example, was 57% greater in plants exposed to daylength extensions from incandescent lamps than fluorescent lamps (*6*). Thus, while radiant flux density (*10*), temperature (*23*, *24*, *26*, *30*) and photoperiod (*1*, *15*, *26–29*) can cause more profuse branching, reduce plant height and influence carpel development, light quality also exerts a significant influence on soybean growth.

Tanner and Hume (*24*) proposed that a combination of various environmental factors, including the more judicious use of incandescent lamps, may correct the uncharacteristic growth of soybeans in greenhouses and controlled-environment chambers. This paper presents the results of a series of experiments that were initiated in order to verify their proposal (*24*), and to establish the most suitable temperature and light regime for growth and reproduction of soybeans under controlled-environment conditions.

MATERIALS AND METHODS

Seeds of the soybean [*Glycine max* (L.) Merr.] cultivars 'Blackhawk' (I), 'Bragg' (VII), 'Dare' (V), 'Fiskeby' (00), 'Lee' (VI) and 'Ransom' (VII) were planted in 20-cm diameter pots filled with a peat-lite/gravel substrate mix (1:2, v/v) and watered two or three times daily as needed with Phytotron nutrient solution (*11*). Upon expansion of the primary leaves pots were thinned to one seedling per pot. Experiments were conducted either in unshaded, temperature-controlled greenhouses and associated photoperiod rooms, or in the controlled-environment chambers of the NCSU Phytotron (*11*). The photoperiod rooms are equipped with cool white fluorescent and incandescent lamps which provide a relatively low

PPFD of 36 μmol m^{-2} s^{-1} from the fluorescent lamps and 25 μmol m^{-2} s^{-1} from the incandescent lamps, with far-red irradiances (FR, 700–850 nm) of 0.10 W m^{-2} and 4.2 W m^{-2}, respectively. The controlled-environment chambers provide a PPFD of 670–730 μmol m^{-2} s^{-1} from a 10:3 input wattage ratio of fluorescent: incandescent lamps. In the chambers the FR irradiances are 1.1 W m^{-2} and 12.8 W m^{-2}, respectively, from fluorescent and incandescent lamps. PPFD and FR were measured 95 cm below the lamps with a LI-COR quantum/radiometer and sensors. In some experiments the basic light levels were altered and this is noted at appropriate places in the text.

Day temperature was coincident with the high irradiance portion of the photoperiod; for example, when plants were exposed to a 16 h day from a combination of 9 h of high intensity light in the greenhouse and 7 h low intensity light in the photoperiod rooms, the day temperature was coincident with the 9 h greenhouse phase.

Treatments were initiated at emergence (60 h after planting) in randomized blocks of three to five plants and blocks were replicated two to eight times (blocks and replications varied with studies). Experiments were repeated to ensure reproducibility; however, repetitive greenhouse experiments were not considered replicates in time due to the inherent differences in natural light between experiments.

RESULTS

A preliminary study was conducted to determine whether there might be an advantage in using a continuously variable diurnal temperature program derived from weather records in comparison to constant or alternating day/night (D/N) temperature regimes programmed for equivalent average daily temperatures (Table 1). Plants were tallest and had the greatest fresh weight under the alternating temperature regime, therefore, subsequent experiments were designed using similar alternating D/N temperature differentials.

In the first study the growth of 'Ransom' and 'Fiskeby' was compared in response to exposure to several different combinations of D/N temperature and

Table 1. Growth of 'Bragg' soybean plants after 28 days under three different temperature regimes programmed for an equivalent average daily temperature of 26.5°C with a 12 h photoperiod

Temperature (°C)	Stem length (cm)	Fresh weight (g)	Leaf area (cm^2)
Programmed*	65b	43.57b	1622b
29.5 D, 23 N**	73a	46.08a	1706ab
26.5 D, 26.5 N	64b	43.89b	1779a

Different letters within the same column indicate significance at the 5% level by Duncan's multiple range test.

* Diurnal temperature program based on weather records with 33°C max, 19.5°C min.

** D/N temperature regime equivalent to 26.5°C constant.

daylength differentials: Seedlings were grown under either 22/18°C or 26/22°C D/N temperatures in chambers programmed for a 9 h high intensity light period and either a 15 h dark period for short-day (SD) treatments, or with a 3 h low intensity interruption from the incandescent lamps during the middle of the dark period for LD treatments. Upon expansion of the third trifoliolate leaf, all plants were placed under a 9 h SD photoperiod at 26/22°C until anthesis, followed by a 30/26°C D/N temperature regime until harvest on day 70 (Table 2). For 'Ransom' the only significant effect of the seedling D/N temperature treatment was on days to anthesis, and for seedlings exposed to LD there was also an effect on pod weight (Table 2). 'Ransom', however, is a SD sensitive cultivar and therefore, the SD or LD exposures given at either temperature produced highly significant differences in all measured parameters (Table 2). In contrast, 'Fiskeby' which is day neutral (DN), responded more strongly to seedling temperature than to photoperiod. Seedlings of 'Fiskeby' grown under 22/18°C were smaller and bloomed later than those under 26/22°C (Table 2). 'Fiskeby' seedlings grown initially at 26/22°C did exhibit a number of significant responses to photoperiod treatment wherein LD-exposed plants were larger, but had smaller pods (Table 2).

A subsequent study examined growth of 'Ransom' and 'Fiskeby' under alternating D/N temperatures of 18/14, 22/18, 26/22 and 30/26°C and exposed to either continuous SD or LD photoperiods, or to two initial weeks of LD followed by SD (Fig. 1). For both cultivars growth was slower at D/N temperatures of 18/14 and 22/18°C than at 26/22 and 30/26°C as evidenced by main stem node number and length of the main stem (Fig. 1). The increases in node number and stem length as functions of temperature were more pronounced on LD or when SD were preceded by the period of LD, than on continuous SD (Fig. 1). Mean pod weight for 'Fiskeby' after 7 weeks under 22/18°C and continuous SD or under the 2-week

Table 2. Growth of 'Ransom' (R) and 'Fiskeby' (F) soybeans after various pretreatment D/N temperature and photoperiod combinations followed by 26/22°C and SD until anthesis, then 30/26°C until harvest on day 70

Pretreatment		Node number		Stem length (cm)		Branch length (cm)		Days to anthesis		Pods>2 cm			
D/N Temp.	Photo-period*									Number		Weight (mg)	
		R	F	R	F	R	F	R	F	R	F	R	F
26/22	SD	7	10	57	82	24	26	27	30	48	42	898	1141
26/22	LD	14	12	180	129	66	48	42	29	121	73	688	1066
22/18	SD	7	8	44	46	24	27	33	35	38	43	873	1018
22/18	LD	15	8	191	55	68	34	44	35	123	49	560	1017
F-test significance:													
Temp./SD		ns	**	ns	**	ns	ns	**	**	ns	ns	ns	*
Temp./LD		ns	**	ns	**	ns	**	**	**	ns	**	**	ns
SD/LD, 26/22		**	**	**	**	**	**	**	**	**	**	**	ns
SD/LD, 22/18		**	ns	**	ns	**	**	**	ns	**	ns	**	ns

ns=differences are not significant; * and **=differences significant at the 5% and 1% level, respectively.

* SD photoperiod=9 h; LD photoperiod=9 h plus 3 h interruption.

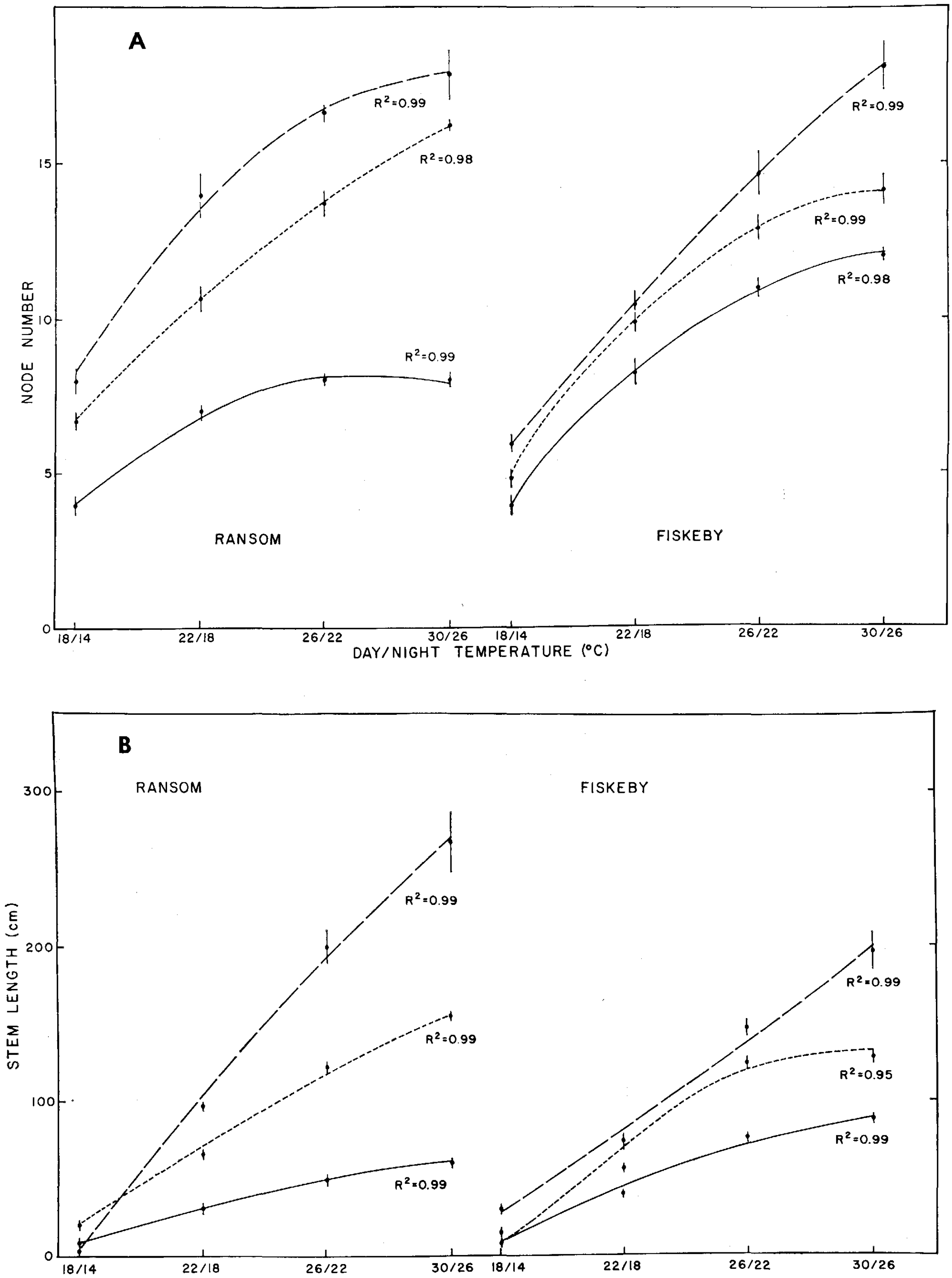

Fig. 1. Effect of D/N temperature on development of 'Ransom' and 'Fiskeby' soybeans after seven weeks on continuous SD (solid line), continuous LD (dashed line) or SD preceded by two weeks of LD (small dashed line). A=node number; B=stem length.

LD pretreatment, was 46% less than pod weight of plants grown at 26/22 and 30/26°C (data not shown). 'Fiskeby' grown under continuous LD produced similar-sized pods at the three higher temperature regimes; however, pod weights at 30/26 and 26/22°C LD were only 53% of weights produced on plants under continuous SD at these temperatures. 'Ransom' produced no pods under continuous LD at any temperature regime, nor under 22/18°C when plants received the 2-week LD pretreatment. Pods were produced at 26/22 and 30/26°C, but under the LD pretreatment pod weights were reduced by 44% compared to continuous SD. No pods were produced at 18/14°C for either cultivar.

The amount of light received by plants in controlled-environment rooms can be altered by varying the number of hours of exposure to high-intensity light, or by changing the radiant flux density. An experiment which increased the number of hours of light per day from 9 to 13 at a PPFD of 635 μmol m^{-2} s^{-1} did not result in significant differences in growth. Although stem elongation in 'Ransom' was reduced with light periods greater than 9 h (Fig. 2), weight per unit length was not altered significantly (data not shown). A reduction in PPFD for a fixed time did not alter the time required for flowers to reach anthesis, but as the light level was reduced, stem elongation in 'Blackhawk' tended to increase while weight per unit length decreased (Fig. 3).

An LD response can be obtained by extending the day with light from low-

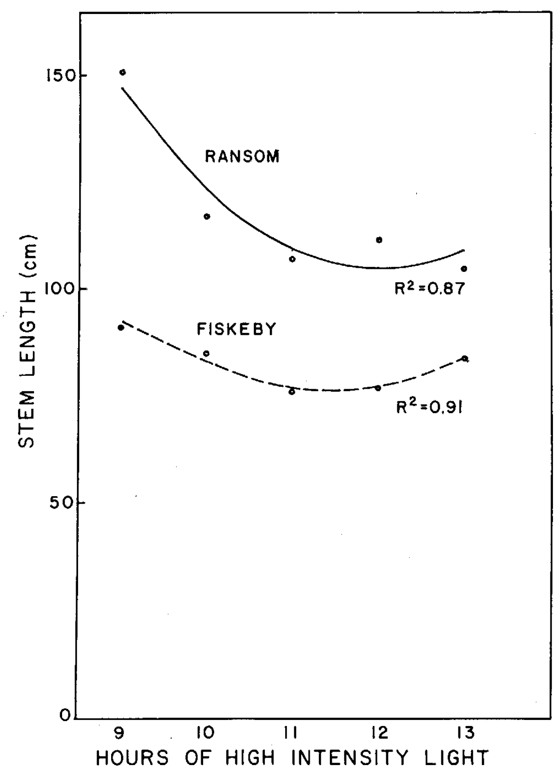

Fig. 2. Growth of 'Ransom' and 'Fiskeby' soybeans after five weeks under various durations of a PPFD of 635 μmol m^{-2} s^{-1}, each extended to 13.5 h with incandescent light at a PPFD of 44 μmol m^{-2} s^{-1} at 26/22 D/N temperature.

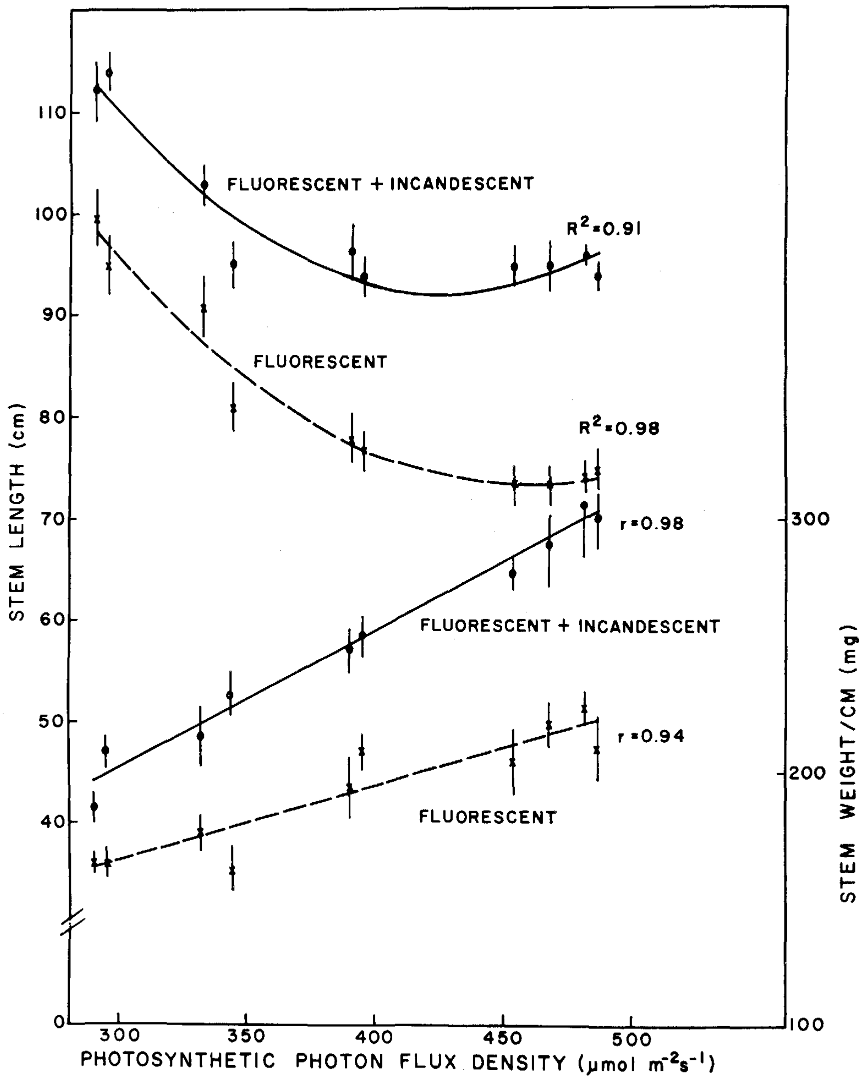

Fig. 3. Effect of PPFD and light quality on development of 'Blackhawk' soybean after 33 days at 26/22 D/N temperatures and 16 h light periods.

intensity lamps or by using the more energy efficient method of briefly interrupting the dark period with the photoperiod control light source. A 1 h interruption during the middle of a 15 h dark period with an illuminance of 1.1 klx from incandescent lamps (PPFD of 25 μmol m^{-2} s^{-1}) inhibited flowering of 'Ransom' as much as a 16 h daylength (Table 3). The 1 h interruption of the 15 h dark period, however, did not delay flowering of 'Blackhawk', and even a 4 h interruption in the dark period did not inhibit flowering as much as a 20 h day extended by incandescent light (Table 3). Plants exposed to dark interruptions also possessed shorter stem lengths than those exposed to daylength extensions (Table 3).

Oftentimes when experiments with soybeans are conducted in controlled-environment chambers or greenhouses with supplemental photoperiod rooms, a single daylength is used throughout the life cycle. A photoperiod that corresponds

Table 3. Growth and flowering of 'Ransom' (R) and 'Blackhawk' (B) soybeans under various durations of photoperiod extensions and interruptions from fluorescent and incandescent light sources as compared with a 9 h SD photoperiod

Treatment and light source	Days to anthesis		Stem length (cm)	
	R	B	R	B
Extension:				
11 h, fluorescent	—	30d	—	41.0d
11 h, incandescent	—	60a	—	166.0a
7 h, incandescent	63a	—	157.2a	—
Interruption:				
1 h, incandescent	63a	29de	100.0b	35.4d
2 h, incandescent	—	39c	—	55.4c
4 h, incandescent	—	48b	—	90.3b
9 h SD	30b	28e	28.8c	18.4e

Different letters within the same column indicate significance at the 5% level by Duncan's multiple range test.

Table 4. Influence of daylength on growth and flowering of 'Ransom' soybeans after 62 days

Photoperiod* (h)	Node number	Stem length (cm)	Branch weight (g)	Days to anthesis
12.5	9c	70d	17.85e	35d
13.5	12b	103c	74.72b	40c
14.5	17a	160a	113.54a	62b

* 9 h in a 26°C greenhouse followed by 15 h at 22°C in photoperiod rooms programmed to extend the day to the indicated number of h with incandescent lamps.
Different letters within the same column indicate significance at the 5% level by Duncan's multiple range test.

to the sunrise to sunset period at an early planting date at Raleigh, NC at 36°N lat. (e.g., April 26) is 13 h, 30 min. 'Ransom' is a commonly grown cultivar at this locale. A photoperiod duration study revealed that in comparison to growth at 13 h, 30 min, daylengths 1 h shorter (12 h, 30 min) tended to reduce branching, while daylengths 1 h longer (14 h, 30 min) tended to delay flowering and stimulated elongation of the main stem (Table 4).

Experiments were conducted to compare the effect of two constant daylengths based on either sunrise to sunset (13 h, 39 min), or with the addition of civil twilight (14 h, 35 min) with the simulations of the natural progression of both of these periods, beginning on May 1. The two sunrise to sunset progressions began with 13 h, 39 min, or with 14 h, 35 min. The progressions then increased at 1 min, 11 s and 1 min, 16 s, respectively, for the two daylengths, up to day 49. From day 49 to day 58 the two progressive daylengths were held constant at 14 h, 35 min, 48 s and 15 h, 35 min, 48 s, respectively. Thereafter, the daylengths progressively decreased at rates of 1 min, 21 s and 1 min, 49 s, respectively, until harvest. After 79 days plants were harvested. Soybeans grown under the continuous 13 h, 39 min

Table 5. Growth of 'Ransom' soybeans after 79 days exposure to various simulated natural daylength progressions at 35°N latitude beginning on May 1 and using fluorescent or incandescent light sources

Photoperiod and light source	Days to anthesis	Node number	Stem length (cm)	Stem weight (mg/cm)	Mean branch length (cm)	Mean branch weight (mg)
13 h, 39 min:						
Fluorescent	35	9	42	509	26.2	1220
Incandescent	38	10	59	756	32.1	1520
Sunrise-sunset:						
Fluorescent	40	10	45	543	28.6	1610
Incandescent	44	11	62	903	42.8	1950
14 h, 35 min (=13 h, 39 min+civil twilight):						
Fluorescent	51	15	87	582	41.5	1753
Incandescent	66	19	127	936	47.7	1848
Sunrise-sunset+Civil twilight:						
Fluorescent	76	16	110	540	59.0	1650
Incandescent	83*	20	137	1009	66.3	1800
$LSD_{0.05}$ light source	3	1	4	42	1.7	13
$LSD_{0.05}$ photoperiods	4	1	6	59	2.4	18

* Anthesis occurred on 70% of fluorescent lighted plants and on 50% of the incandescent lighted plants. Date estimated for plants not at anthesis stage by day 79.

daylength were the first to bloom, had the shortest stems (Table 5), and produced an average of 82 pods greater than 2 cm long with a mean weight of 660 mg. In contrast, soybean plants grown under the progressive daylength regime programmed to begin with 13 h, 39 min produced only 1 pod over 2 cm long with a mean weight of 170 mg (data not shown). Longer days based on either the continuous 14 h, 35 min regime, or its respective progressive daylength regime, delayed anthesis and promoted stem height and branch length (Table 5). For any of the four daylength extensions when incandescent lamps were used as the light source days to anthesis were delayed, plants produced more main stem nodes on longer stems, had longer branches and heavier stems and leaves (Table 5).

Incandescent lamps added to the main fluorescent light source of a controlled-environment room, even at the relatively low fluorescent: incandescent ratio of 19:1, increase the FR radiation more than seven-fold and alter the R/FR ratio from 10.2 : 1 to 1.9 : 1. In experiments with 'Blackhawk', 'Fiskeby' and 'Ransom' grown under lighting regimes composed of only fluorescent lamps, or fluorescent plus incandescent lamps it was found that time to anthesis was not altered by changes in the R/FR ratio under inductive photoperiods (data not shown). The addition of FR radiation did induce stem elongation in 'Blackhawk' and 'Ransom' (Table 6), and contributed to greater stem and leaf weights for all three cultivars (Table 6).

Time of anthesis for many SD plants appears unaffected by the differences in quality of fluorescent and incandescent light sources, therefore, extending the greenhouse day with either fluorescent or incandescent light should be equally effective. Yet in the sunrise to sunset study anthesis for 'Ransom' was obviously delayed when daylengths were extended with incandescent light rather than fluo-

Table 6. Growth of 'Ransom' (R), 'Fiskeby' (F) and 'Blackhawk' (B) soybeans after 35 days at 26/22 D/N temperatures in controlled environment chambers lighted with fluorescent lamps or a combination of fluorescent and incandescent lamps

Light source	Stem length (cm)			Stem weight (mg/cm)			Mean leaflet weight (mg)		
	R	F	B	R	F	B	R	F	B
Fluorescent	77	72	76	187	185	158	664	689	526
Combination	97*	71	87*	234*	213*	194*	835*	841*	588*

* Differences within columns are significant at the 5% level when followed by "*". Photoperiods were 13.5 h for 'Ransom' and 'Fiskeby', and 16 h for 'Blackhawk'.

Table 7. Growth of 'Bragg' (B), 'Lee' (L), 'Ransom' (R) and 'Dare' (D) soybeans after 60 days under various daylengths and light sources

Daylength (h) and light source	Node number				Stem length				Days to anthesis			
	B	L	R	D	B	L	R	D	B	L	R	D
13.5, Incandescent	13	9	12	12	89	61	71	60	38	37	38	35
13.5, Fluorescent	13	9	11	11	61	38	43	44	37	34	37	38
14.5, Incandescent	22	15	18	15	167	120	114	93	62	59	63	48
14.5, Fluorescent	19	13	17	15	103	73	79	68	58	48	53	49
F-test significance:												
DL/Incandescent	**	**	**	**	**	**	**	**	**	**	**	**
DL/Fluorescent	**	**	**	**	**	**	**	**	**	**	**	**
Inc/Fl, 13.5 h	ns	ns	ns	ns	**	**	**	**	ns	*	ns	**
Inc/Fl, 14.5 h	**	**	ns	ns	**	**	**	**	**	**	**	ns

ns=differences are not significant; * and **=differences significant at the 5% and 1% level, respectively.

rescent, particularly as the duration of the daylength increased (Table 5). In a subsequent study the response to light source by four soybean cultivars, 'Bragg', 'Dare', 'Lee' and 'Ransom' which are often grown in the same latitudinal range, was compared. Under a 13.5 h photoperiod time to anthesis was not altered by light source (Table 7). Subsequent reproductive development, however, was altered with pod number and weights increasing 46% in plants receiving the daylength extension from the fluorescent light source (data not shown). When the photoperiod was increased to 14.5 h the time to anthesis was significantly shorter under the fluorescent daylength extension when compared to the incandescent extension for three of the cultivars; anthesis in 'Dare', however, was unaffected by light source treatment (Table 7).

Flowering of 'Blackhawk' is much more insensitive to fluorescent light than soybean cultivars grown in lower latitudes such as 'Ransom', but the degree of insensitivity exhibited by 'Blackhawk' is dependent on the length of the photoperiod. In an earlier study, a 16 h photoperiod, for example, had only a slight inhibitory effect on time of anthesis (4–5 days) when compared with the effect of a 9 h photoperiod, and little effect of light source could be detected (*25*). Pod development, however, had a shorter critical photoperiod than flowering, and under an incan-

Table 8. Growth and reproduction of 'Blackhawk' soybeans after 60 days under SD and various daylength extensions using incandescent (Inc) or fluorescent (Fl) light applied after three different stages of development

Light regime	Stem length (cm)			Days to anthesis			Pods>2 cm Number			Pods>2 cm Weight (mg)		
	P	I	A	P	I	A	P	I	A	P	I	A
9 h, SD*	37d	50d	70b	28d	30b	32a	27b	33b	46a	745b	819b	846a
20 h, Inc	160b	153b	123a	60a	59a	32a	0	0	8b	0	0	375b
20 h, Fl	73c	73c	73b	32c	32b	32a	50a	50a	50a	959a	959a	959a
20 h, Inc & Fl	168a	168a	118a	58b	58a	31a	0	0	8b	0	0	316b
$LSD_{0.05}$, PIA		3			1			3			41	

P=treatments begun at planting; I=treatments begun after flower initiation; A=treatments begun after anthesis.
Different letters within the same column indicate significance at the 5% level by Duncan's multiple range test.
* All plants received 9 h in the greenhouse, followed either by 15 h dark period or 11 h daylength extensions as described in table.

descent, 16 h photoperiod pod development was inhibited but not under fluorescent (data not published). In this study, under a 20 h photoperiod the fluorescent insensitivity became apparent for both flowering and pod development (Table 8). Microscopic dissections of 'Blackhawk' apices revealed that flower initiation occurred within 13–15 days regardless of light source, but was delayed 5 days when the photoperiod was extended from 16 to 20 h with the incandescent treatment (*25*). Exposure to incandescent, or to a mixture of incandescent and fluorescent light, however, from time of planting delayed anthesis by as much as 30–32 days when compared to SD treatments, whereas fluorescent light delayed anthesis by only 4 days (Table 8). When the light treatments were started after anthesis, significant effects of light quality on pod development were obtained with incandescent or with incandescent mixed with fluorescent, reducing the number and weight of pods over 2 cm (Table 8). The usage of incandescent light for photoperiod lighting also induced stem elongation in 'Blackhawk' (Table 8) as in other cultivars examined (e.g., Tables 3, 5, 6 and 7).

DISCUSSION

The photoperiod control system of soybeans, when grown in the field, should be sensitive to civil twilight illuminance levels (*1*). In practice, however, extending the photoperiod by adding the duration of civil twilight delayed flowering. This was attributed to a lengthened rate of floral development as well as prolonged vegetative growth at the shoot apex. Sunrise to sunset photoperiod durations on May 1 at the field latitudes where individual cultivars are normally grown seems to be an effective method of selecting a photoperiod that will result in growth and reproduction similar to that which is found in the field for a given cultivar at its locale.

Increased plant height obtained with lengthened photoperiods is chiefly the result of delayed initiation of flower primordia in the terminal meristem and prolongation of its vegetative, leaf initiating phase of development (*1*, *28*). Increased duration of exposure to incandescent light commonly used to extend the day, however, also contributes to significant internode elongation. Stem elongation is a function of the fraction of phytochrome in the FR absorbing form, P_{fr}; and the magnitude of the elongation resulting from a given phytochrome photoequilibrium depends on how long that equilibrium is maintained (*31*, *32*). The R/FR ratio of 1.08 : 1.0 emitted by incandescent lamps used for photoperiod control thus results in more stem elongation than the higher, 9.24 : 1.0 R/FR ratio emitted by cool white fluorescent lamps, and such elongation is enhanced as daylengths and duration of incandescent exposures are increased. Moreover, the practice of adding incandescent lamps to the main fluorescent light source of controlled-environment rooms, even at the relatively low fluorescent/incandescent ratio of 19 : 1, increases the FR radiation sufficiently to induce a significant increase in stem length.

The marked difference in the sensitivity of the photoperiod control system of different soybean cultivars to fluorescent light contradicts traditional action spectra data (*18*, *19*). 'Blackhawk' plants grown under a basic greenhouse day extended with fluorescent light, or in a growth chamber lighted only with fluorescent lamps and exposed to photoperiods from 14.5 to 16 h did not exhibit excessive internode elongation and produced large numbers of pods. Results obtained with cultivars that are insensitive to fluorescent light and are uninhibited by dark period interruptions raises questions about the role of phytochrome control of reproduction which cannot be answered here. Future experiments will examine this question and test the role of the high energy reaction described by Schneider *et al.* (*22*).

Simulation of key environmental parameters, such as programming the natural seasonal progression of daylength, adequately controlled reproduction and modified growth sufficiently to produce compact, non-etiolated plants. Similar results were obtained in greenhouses with auxiliary photoperiod control from fluorescent lamps, and in plant growth chambers programmeds for D/N temperatures of 26/22°C with a daylength corresponding to sunrise to sunset on May 1 at the field latitude, and a PPFD of at least 400 μmol m^{-2} s^{-1} from the fluorescent lamps. Simulation of "natural" conditions as has been done successfully with tobacco (*21*), extends the time to reach maturity, however, for soybeans. Such response, thus, may limit the usefulness of this procedure, particularly when replication of the 'field phenotype' of soybean is not a necessary requirement to achieve the experimental goals.

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