

CIAT - Col.
000114

Technical Bulletin No. 2
November 1972

Folleto Técnico No. 2
Noviembre 1972

Natural daylengths for photoperiod sensitive plants

Duración del día para la reacción fotoperiódica en plantas

Duração do dia para reação ao fotoperíodo em plantas

CIAT
BIBLIOTECA
44886

C. A. FRANCIS

6672



Centro Internacional de Agricultura Tropical
Cali - Colombia

NATURAL DAYLENGTHS FOR PHOTOPERIOD SENSITIVE PLANTS* **

C. A. Francis***

Sensitivity in many crop species to changes in natural daylength from one latitude or season to another has a pronounced effect on plant development and eventual production. This sensitive reaction also limits the range of adaptation of commercial hybrids and varieties, and makes the exchange of germ plasm among improvement programs very difficult. Although factors such as temperature, moisture, insect/disease complexes, and others also contribute to adaptation or its absence, the single factor "photoperiod" is the one with most striking effects on plant development. Also, it is possible to measure and study the influence of daylength, and by this process develop materials insensitive to photoperiod changes. Then one may proceed to evaluate temperature and other factors without the confounding effects of photoperiod.

The tremendous value of photoperiod insensitivity has been demonstrated clearly in the new varieties of wheat and rice developed by the International Wheat and Rice Programs in Mexico and the Philippines, respectively. These varieties move easily across latitudes and around the globe, and currently form a major part of the basis for the green revolution. The same advances will soon be made in other crops, but more information on each crop and the reaction to different natural photoperiods must be determined in order to push back the barriers to wider adaptation.

An important step in this process is the definition of natural photoperiods. Most elementary texts in geography include curves which show hours of sunlight and "darkness" (i.e., non-sunlight hours). These are based on time of sunrise and time of sunset. However, the critical light intensities that control photoperiodic reactions in plants are considerably lower than levels occurring only during the hours of sunlight. Thus, the "effective" daylength for a photoperiod-sensitive reaction may be much longer than the hours of sun. The "twilight" zone is important.

To adequately evaluate plant development data from past plantings or to choose locations between which one may alternate seasons in a field program to develop insensitive genotypes, the critical number of hours of effective light and darkness must be known. This is equally important if natural daylengths are to be extended artificially in the field. In

* Adapted [from technical journal article, "Effective daylengths for the study of photoperiod sensitive reactions in plants". C. A. Francis. *Agronomy Journal* 62: 790-792 (November-December). 1970 (1).

** Summaries in Spanish and Portuguese appear on Page 32.

*** Maize Breeder, Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia, S.A.

a recent field study of maize in the tropics (2), we used 5 hours of additional light to shorten the dark period. Light intensities above the critical levels of 5 foot candles and 1 to 2 foot candles were effective in delaying floral differentiation by about 20 and about 5 days, respectively, in photoperiod sensitive genotypes (one foot candle is approximately equal to 10.76 lux). These critical intensities have not been established for many crop species. Therefore, to extend the application of these curves of "Photoperiod Effective Hours" to many species and locations, calculations were made using four critical intensities: 10, 5, 2 and 1 foot candle (108, 54, 22 and 11 lux), latitudes from 70° N to 60°S, and 15-day intervals through the year. These curves are reproduced in bulletin form to allow increased size and accuracy in their use, compared to the original publication (1). The tables of original data from which the curves were drawn are also included to give more detail and precision for each latitude and season.

MATERIALS AND METHODS

To calculate the number of hours in the day with a light intensity above a certain level, the time in the morning at which that intensity is reached and the time in the evening at which it is passed must be known. The Nautical Almanac (5), published yearly by the U.S. Naval Observatory, gives the times of Civil twilight (sun 6° below horizon), sunrise, and sunset. From tables in the 1965 edition of this almanac, the hours of sunlight and hours with a light intensity above Civil twilight were calculated for latitudes at 10° intervals from 70°N to 60°S. The light intensity of the sun on a clear day with the disk near the horizon is 1,885 Lamberts (3). This intensity is approximately 42 ft.-c. Factors for light energy conversions are given in Table 1. Before the sun reaches the horizon, the light intensities on a clear day at -6°, -5°, -4°, -3°, -2°, and -1° (angle of sun below horizon) are 2, 5, 13, 40, 113, and 250 lux, respectively (4). These values, in the order given, are about 0.2, 0.5, 1.2, 3.7, 10.5, and 23.2 ft.-c. From these data a light intensity curve is drawn for sun angles below the horizon from Civil twilight to sunrise. This curve may be reversed for the period from sunset to Civil twilight in the evening. The sun angle below the horizon at which each specific foot candle intensity is reached on a clear day is then determined. Because of the essentially uniform angular velocity of the earth relative to the sun, the ratio of the degrees below the horizon for a specific light intensity to -6° gives the proportion of the time between Civil twilight and sunrise, and between sunset and Civil twilight, which is above the critical intensity. This time is added to the hours of sunlight to give the total hours per day with an intensity above any chosen level.

Table 1. Approximate factors for light and energy conversions.
Cuadro 1. Factores aproximados para convertir unidades de luz y energía.

Quadro 1. Fatores aproximados para converter unidades de luz e energia.

1 foot candle (ft.-c) = 44.9 Lamberts
1 foot candle (ft.-c) = 10.76 lux
1 Langley (1 g cal/cm ² /min) = 6,800 foot candles

RESULTS AND DISCUSSION

Natural photoperiods for all months of the year and for latitudes from 70° N to 60° S are summarized in four figures. These curves indicate the number of hours of light above intensities of 10 foot candles (108 lux), 5 foot candles (54 lux), 2 foot candles (22 lux), and 1 foot candle (11 lux). Figures 1 through 4 give these photoperiods for clear days and no obstructions on the horizon. It is obvious that heavy cloud cover during early morning or late afternoon, such as that which occurs in the tropics during the monsoon season, significantly reduces the effective photoperiod for a particular latitude and date and extends the dark period crucial for photoperiod sensitive reactions. Scattered high clouds near the horizon, on the other hand, could reflect sunlight from below the horizon and extend the photoperiod for several minutes. Although the atmospheric path is the same at all latitudes and zero solar elevation, the amount of moisture and dust in the atmosphere may vary significantly with latitude and season, and thus influence the effective photoperiod. These variations in natural effective photoperiods are minor, however, relative to changes with latitude and season, and are impossible to calculate.

The calculations for these curves have been based on foot candles because of the widespread availability and use of inexpensive foot candle meters. These critical intensities may be converted to lux or Langleys using the approximate conversion factors listed in Table 1.

The exact beginning time of the period with a critical intensity above a certain level for a given latitude and date can be approximated by dividing the number of light hours by 2, and then subtracting this value from the time of solar noon in that location and on that date. The ending time of this period of illumination is found by adding the same value to the time of solar noon. The exact time of solar noon is 12:00 on the dates of the equinoxes, but will vary from 5 to 10 minutes after noon on the date of the December solstice, and 5 to 10 minutes before noon on the date of the June solstice, depending on the latitude. Time of solar noon may be found in tables (5), estimated from the sunrise-sunset curves in a geography textbook, or interpolated from Table 6.

From the preceding Figures 1 to 4, a family of curves may be constructed for a specific latitude or location of interest by interpolating from the curves for each intensity. As an example, one location was chosen from a north latitude and one from a distinct south latitude. This is illustrated in Fig. 5 for Ithaca, New York (Lat. $42^{\circ}25'$ N) and Sao Paulo, Brazil (Lat. $23^{\circ}30'$ S). The hours from sunrise to sunset also are presented in this figure. Note that the scale in hours is different from the other figures. In Ithaca, New York, the 10-ft.-c. photoperiodically effective days are 23 and 26 min longer than sunlight hour days in December and June, respectively. The 1-ft.-c. days are 24 and 26 min longer than the 10-ft.-c. days in December and June, respectively. A figure of this type may be used to rapidly read the number of hours above a critical intensity, and thus the period of darkness, which have

Figure 1. Photoperiod in hours with an intensity greater than ten foot candles (107.6 lux).

Figura 1. Fotoperíodo en horas con una intensidad superior a las diez bujías (107.6 lux).

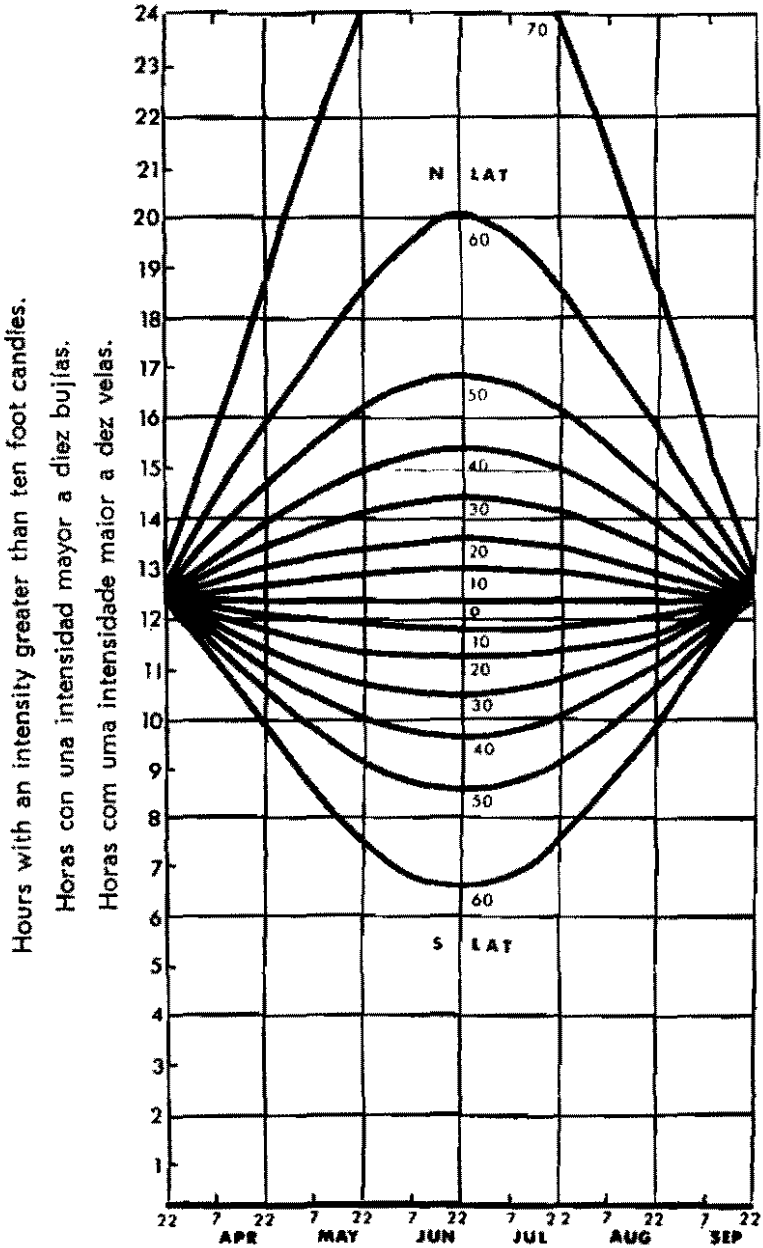


Figura 1. Fotoperíodo em horas com uma intensidade superior a 10 velas (107.6 lux).

Hours with an intensity greater than ten foot candles.
 Horas con una intensidad mayor a diez bujías.
 Horas com uma intensidade maior a dez velas.

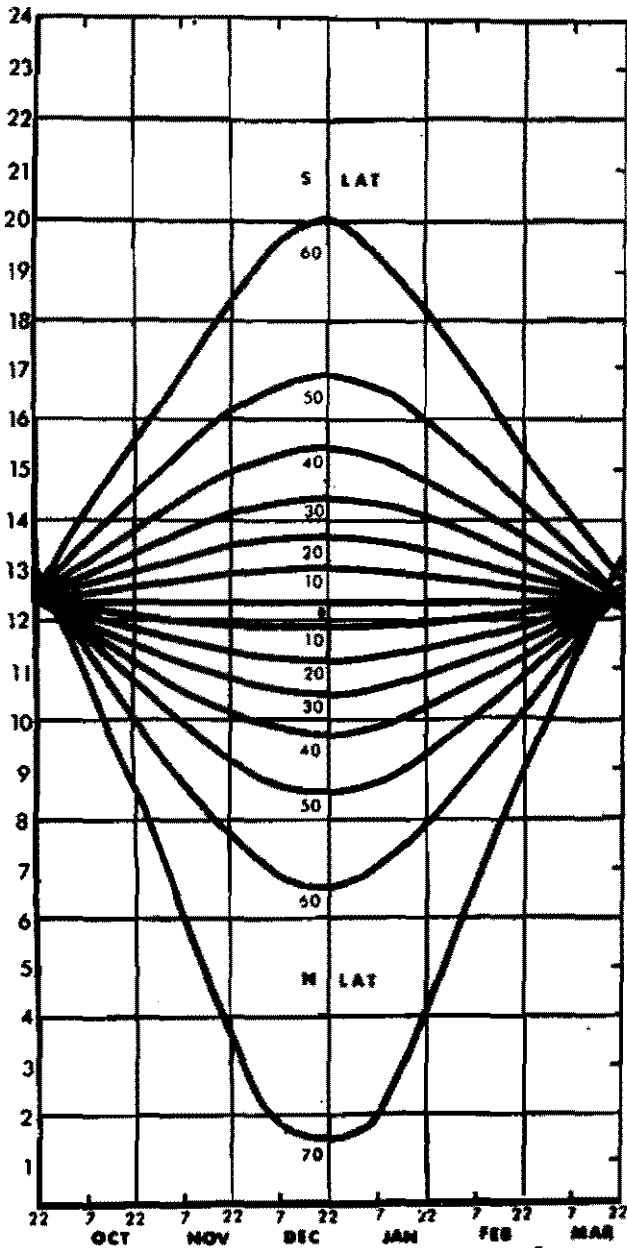


Figure 2. Photoperiod in hours with an intensity greater than five foot candles (53.8 lux).

Figura 2. Fotoperíodo en horas con una intensidad superior a las cinco bujías (53.8 lux).

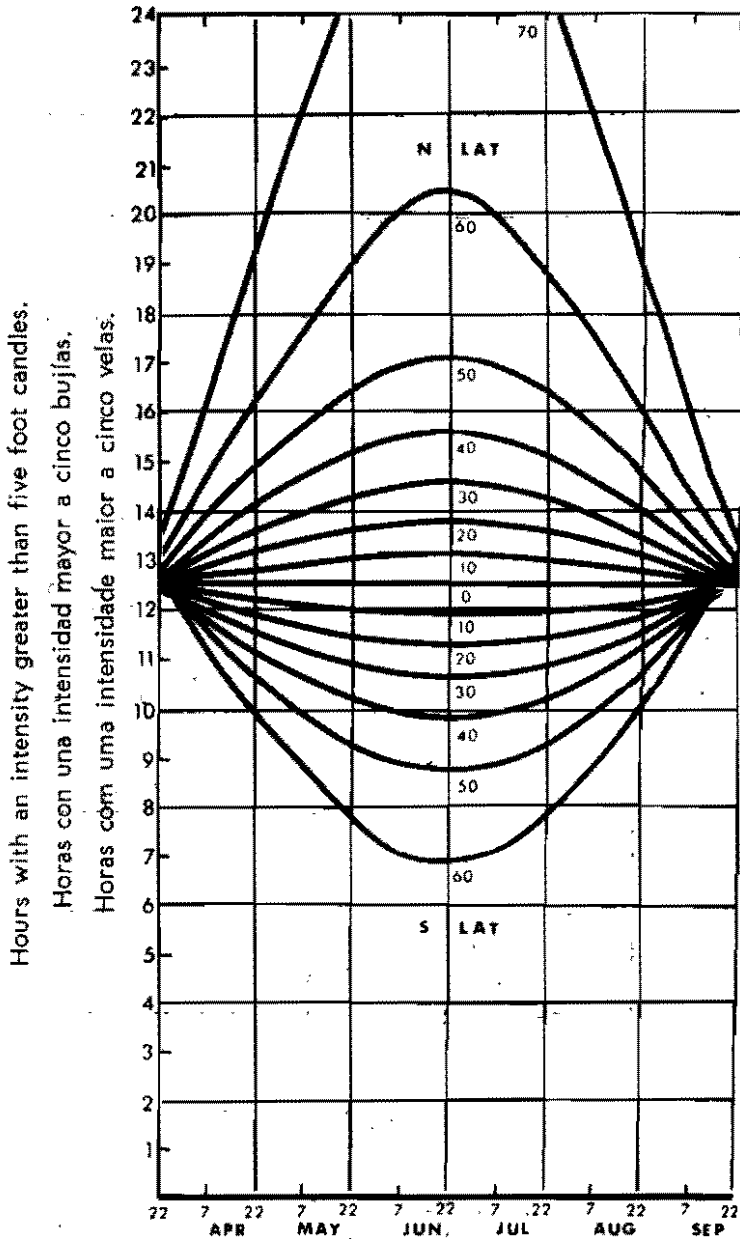


Figura 2. Fotoperíodo em horas com uma intensidade superior a 5 velas (53.8 lux).

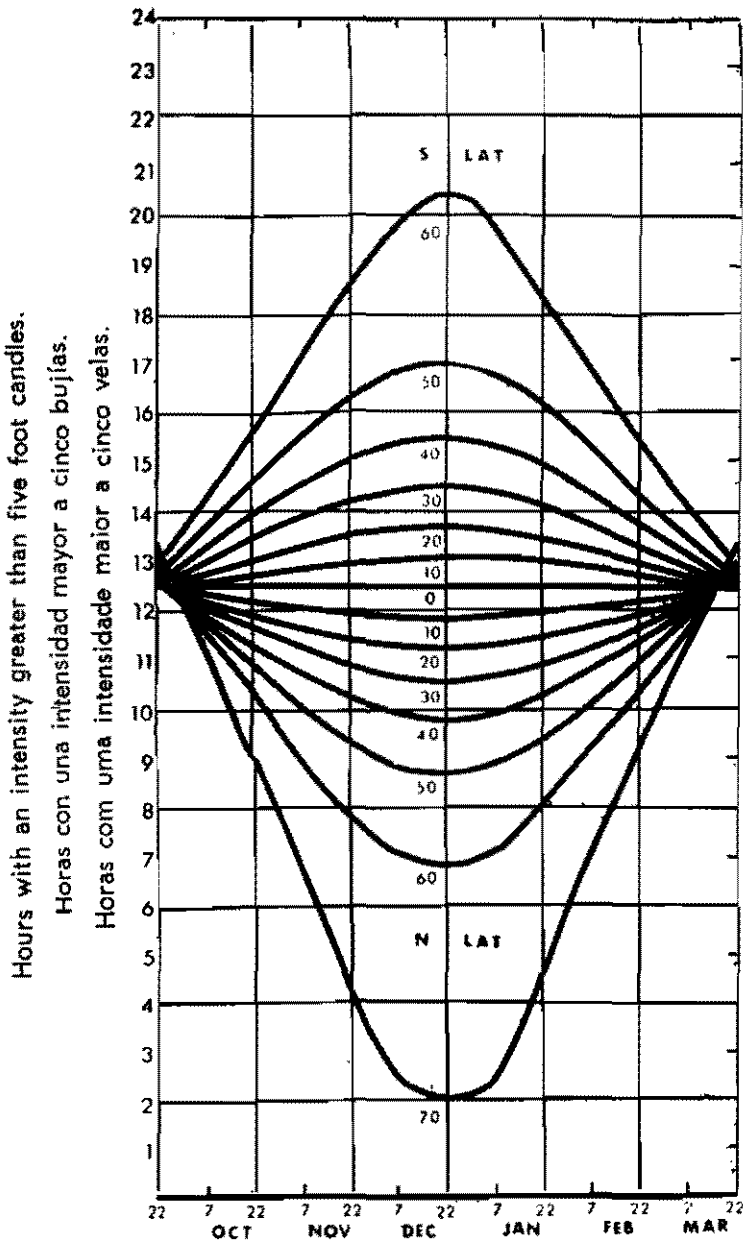


Figure 3. Photoperiod in hours with an intensity greater than two foot candles (21.5 lux).

Figura 3. Fotoperíodo en horas con una intensidad superior a las dos bujías (21.5 lux).

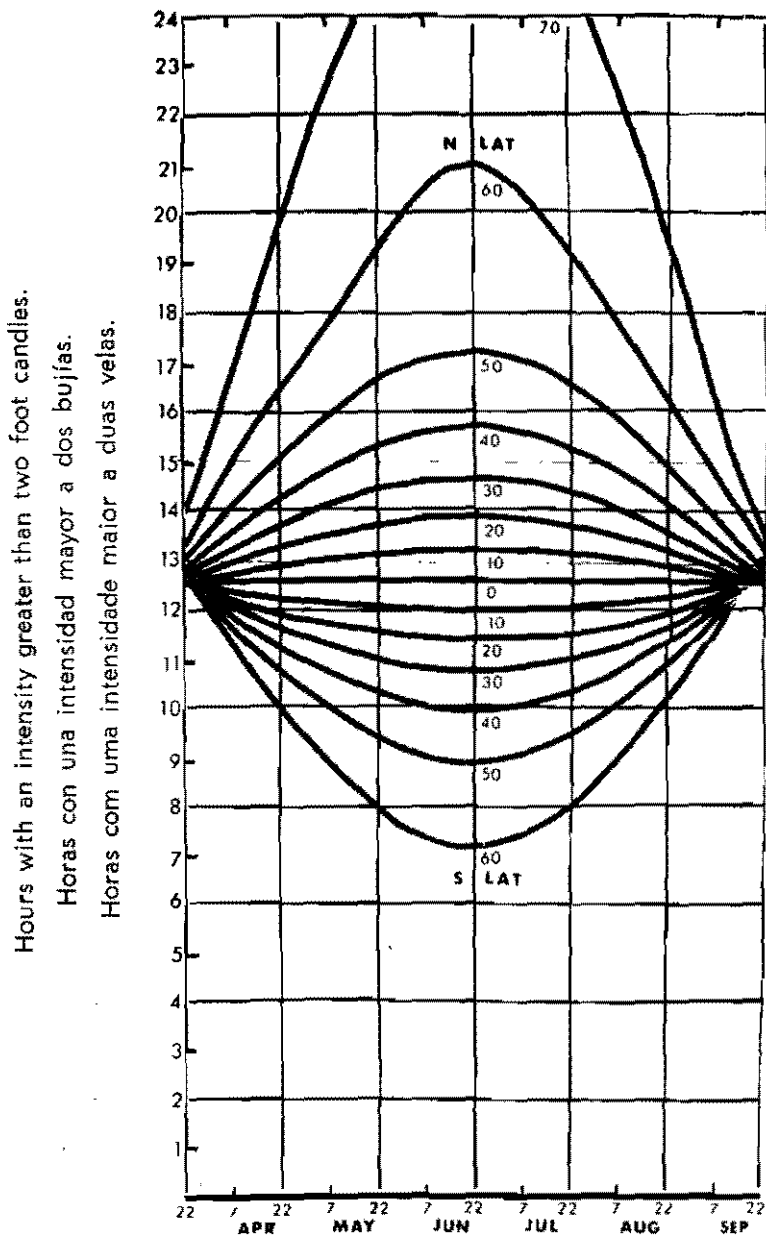


Figura 3. Fotoperíodo em horas com uma intensidade superior a 2 velas (21.5 lux).

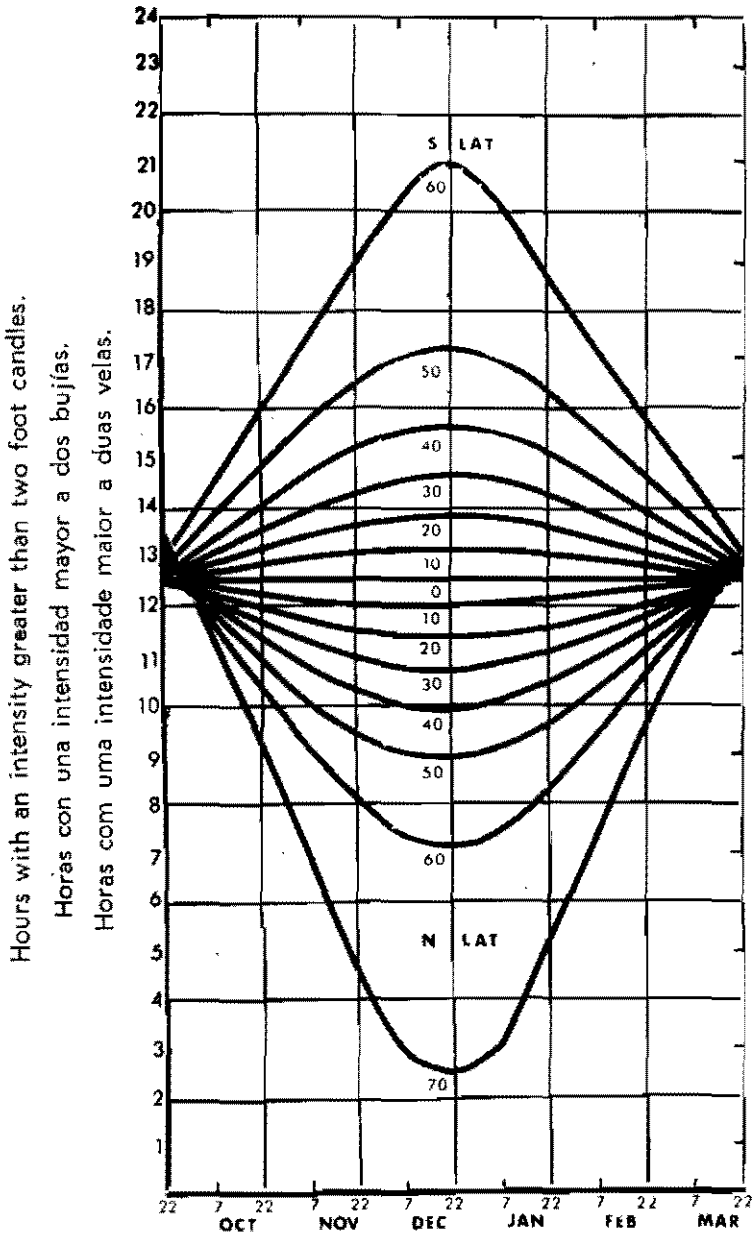


Figure 4. Photoperiod in hours with an intensity greater than one foot candle (10.8 lux).

Figura 4. Fotoperíodo en horas con una intensidad superior a una bujía (10.8 lux).

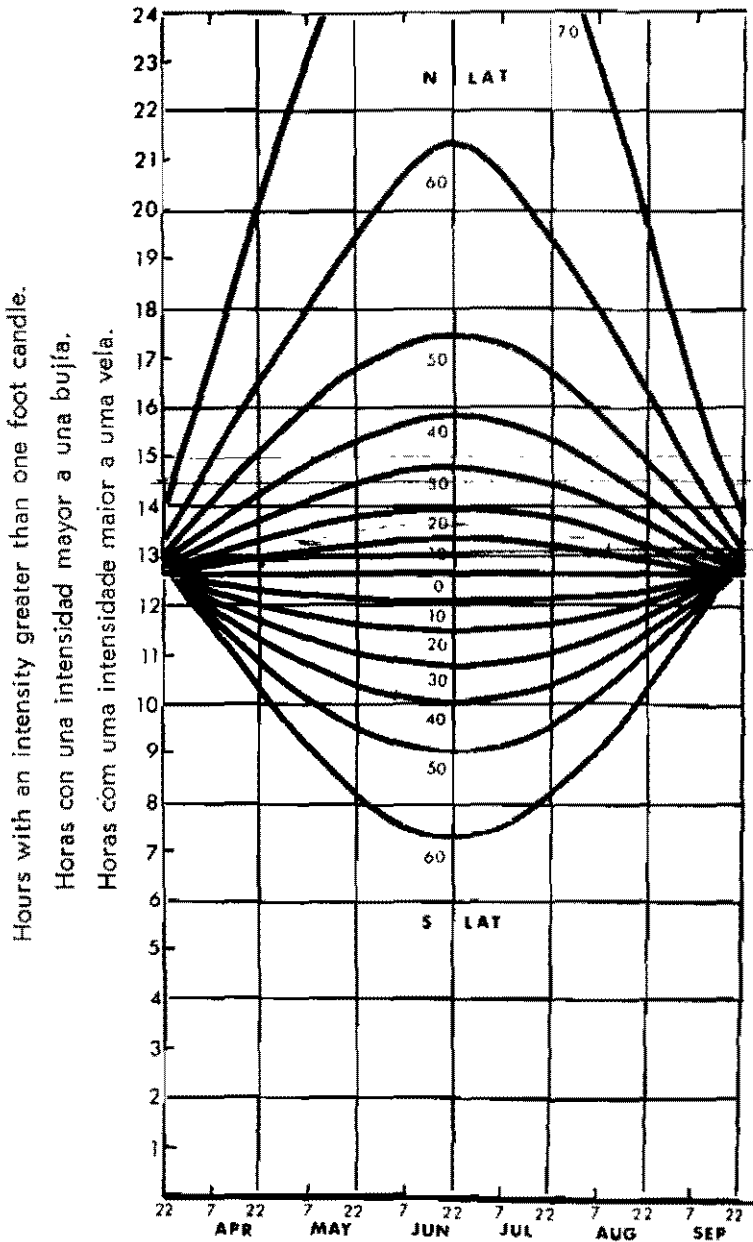


Figura 4. Fotoperíodo em horas com uma intensidade superior a uma vela (10.8 lux).

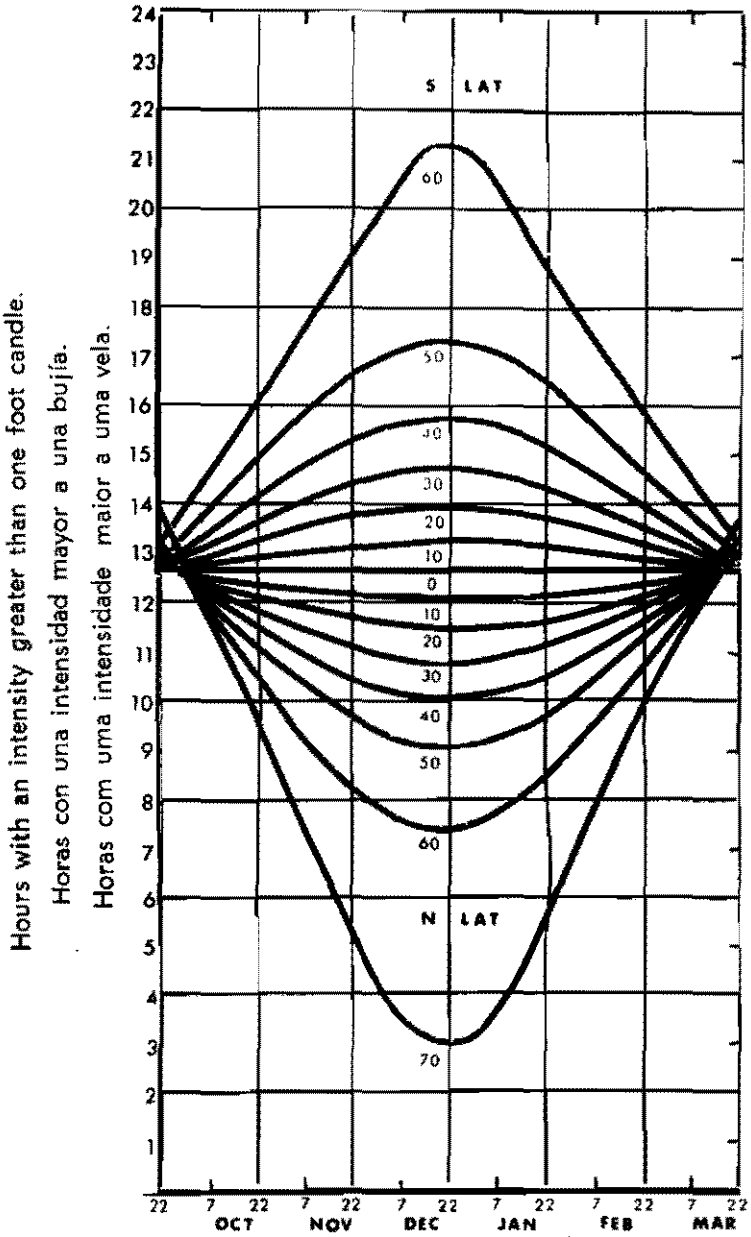
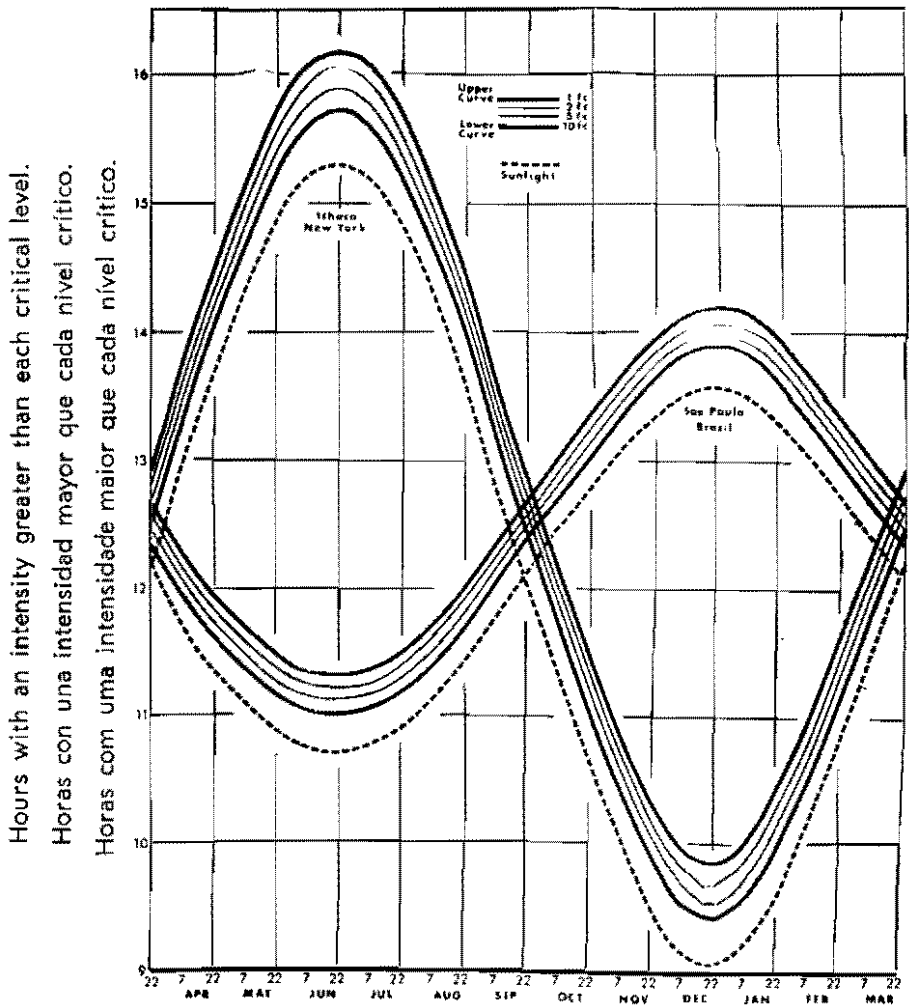


Figure 5. Photoperiod in hours for four critical intensities and two latitudes: Ithaca, New York (Lat. N. $42^{\circ}25'$) and Sao Paulo, Brazil (Lat. S. $23^{\circ}30'$).

Figura 5. Fotoperíodo en horas para cuatro intensidades críticas y dos latitudes: Ithaca, New York, E.U.A. (Lat. N. $42^{\circ}25'$) y Sao Paulo, Brasil (Lat. S. $23^{\circ}30'$).

Figura 5. Fotoperíodo em horas para quatro intensidades críticas e duas latitudes: Ithaca, New York, E.U.A. (Latitude N. $42^{\circ}25'$) e São Paulo, Brasil (Latitude S. $23^{\circ}30'$).



influenced the growth and development of crops in past seasons. It may be used to predict plant response if the crop is planted on a given date. If number of days to floral initiation is correlated with anthesis, days to flowering of specific genotypes when grown in several locations could be compared to determine which factors in the environment were significant in their influence on development.

The precise data from which these curves were drawn are listed in Tables 2, 3, 4 and 5, for the same critical intensities. The data presented are hours and decimals of hours, i.e., 14.50 is 14 hours and 30 min, while 12.75 is 12 hours and 45 min. These tables are useful if the exact hours and minutes of light are needed for a specific location and date. Intermediate dates and latitudes may be interpolated from these tables. Finally, the hours of sunlight for these same latitudes and dates are presented in Table 6, along with exact times of Sunrise and Sunset (5).

CONCLUSIONS

These intensity curves for effective daylengths may be used to evaluate field reactions to photoperiod, one of the important factors which influences the complex pattern of adaptation. Data on both critical intensity and critical daylength are needed for each specific crop to correctly apply the information in these curves to studies of development.

As the factors which influence survival, adaptation and productivity become better understood for each crop species, there will be increased attention given to those dates of planting and harvest which maximize the economic yield per day. Since photoperiod has a direct influence on floral initiation in many sensitive species, the daylength during the early growth and development of the crop is frequently an important factor in determining the optimum planting date. When critical light intensities have been determined for a crop, these foot candle curves will be more precise than similar curves showing hours of direct sunlight. The ultimate value of the information presented here is to aid in the selection of photoperiod insensitive genotypes of most economic species, and thus allow wide adaptation and promote exchange of germ-plasm.

Table 2. Photoperiod in hours with a minimum intensity of 10 foot candles (107.6 lux).

Cuadro 2. Fotoperíodo en horas con una intensidad mínima de 10 bujías (107.6 lux).

Quadro 2. Fotoperíodo em horas com uma intensidade mínima de 10 velas (107.6 lux).

Latitude	January		February		March		April		May		June	
	7	22	7	22	7	22	7	22	7	22	7	22
70°N	1.75	4.29	6.90	9.21	10.96	13.14	15.91	18.72	21.65	24.00	24.00	24.00
60°N	6.98	7.87	9.03	10.33	11.40	12.76	14.44	15.85	17.26	18.58	19.66	20.12
50°N	8.77	9.32	10.05	10.92	11.65	12.59	13.73	14.64	15.51	16.25	16.74	16.90
40°N	9.85	10.21	10.72	11.32	11.83	12.50	13.28	13.92	14.50	14.99	15.30	15.40
30°N	10.64	10.87	11.21	11.62	11.98	12.43	12.97	13.41	13.80	14.13	14.34	14.41
20°N	11.27	11.42	11.63	11.88	12.11	12.38	12.73	13.01	13.25	13.46	13.59	13.63
10°N	11.85	11.91	12.01	12.13	12.23	12.36	12.53	12.67	12.79	12.90	12.95	12.97
0°	12.38	12.38	12.37	12.36	12.36	12.35	12.35	12.36	12.38	12.38	12.38	12.38
10°S	12.95	12.86	12.74	12.60	12.50	12.35	12.18	12.07	11.97	11.88	11.83	11.80
20°S	13.57	13.39	13.17	12.88	12.66	12.36	12.03	11.76	11.54	11.36	11.24	11.22
30°S	14.29	14.02	13.64	13.21	12.85	12.38	11.85	11.43	11.07	10.78	10.59	10.52
40°S	15.23	14.81	14.27	13.63	13.10	12.42	11.65	11.04	10.50	10.07	9.77	9.69
50°S	16.62	15.99	15.15	14.23	13.45	12.51	11.39	10.52	9.74	9.08	8.66	8.52
60°S	19.37	18.10	16.66	15.20	14.05	12.64	11.03	9.73	8.53	7.49	6.78	6.54

Latitude	July		August		September		October		November		December	
	7	22	7	22	7	22	7	22	7	22	7	22
70°N	24.00	24.00	21.43	18.41	15.25	13.00	10.85	8.67	6.37	3.56	1.66	1.44
60°N	19.55	18.43	17.10	15.72	14.05	12.69	11.34	10.01	8.76	7.64	6.84	6.56
50°N	16.69	16.18	15.42	14.56	13.47	12.54	11.61	10.72	9.88	9.18	8.70	8.53
40°N	15.27	14.93	14.45	13.87	13.11	12.45	11.80	11.17	10.60	10.12	9.80	9.68
30°N	14.32	14.10	13.77	13.36	12.84	12.40	11.97	11.52	11.14	10.82	10.59	10.52
20°N	13.57	13.43	13.24	12.98	12.64	12.38	12.08	11.81	11.59	11.38	11.27	11.20
10°N	12.95	12.88	12.78	12.66	12.50	12.36	12.23	12.10	11.98	11.89	11.83	11.82
0°	12.38	12.38	12.37	12.35	12.36	12.35	12.36	12.36	12.38	12.39	12.39	12.39
10°S	11.83	11.88	11.97	12.08	12.23	12.36	12.50	12.64	12.78	12.88	12.95	12.99
20°S	11.25	11.37	11.57	11.78	12.09	12.38	12.67	12.95	13.20	13.43	13.58	13.63
30°S	10.61	10.81	11.09	11.47	11.98	12.42	12.87	13.31	13.73	14.08	14.33	14.41
40°S	9.80	10.10	10.55	11.09	11.82	12.47	13.13	13.79	14.40	14.91	15.28	15.40
50°S	8.71	9.15	9.81	10.60	11.64	12.57	13.50	14.44	15.35	16.14	16.69	16.90
60°S	6.85	7.60	8.65	9.84	11.39	12.73	14.11	15.54	16.98	18.38	19.59	20.10

Table 3. Photoperiod in hours with a minimum intensity of 5 foot candles (53.8 lux).

Cuadro 3. Fotoperíodo en horas con una intensidad mínima de 5 bujías 53.8 lux).

Quadro 3. Fotoperíodo em horas com uma intensidade mínima de 5 velas (53.8 lux).

Latitude	January		February		March		April		May		June	
	7	22	7	22	7	22	7	22	7	22	7	22
70°N	2.34	4.71	7.20	9.46	11.20	13.38	16.19	19.14	22.08	24.00	24.00	24.00
60°N	7.19	8.06	9.21	10.50	11.56	12.92	14.61	16.04	17.48	18.86	20.02	20.54
50°N	8.92	9.46	10.19	11.05	11.77	12.72	13.86	14.78	15.66	16.41	16.91	17.07
40°N	9.97	10.32	10.83	11.43	11.94	12.61	13.39	14.03	14.62	15.11	15.43	15.53
30°N	10.74	10.97	11.31	11.72	12.07	12.53	13.07	13.51	13.90	14.23	14.45	14.51
20°N	11.36	11.51	11.72	11.97	12.19	12.46	12.81	13.10	13.34	13.55	13.68	13.73
10°N	11.94	12.00	12.09	12.21	12.31	12.45	12.61	12.75	12.88	12.99	13.04	13.06
0°	12.47	12.46	12.45	12.45	12.44	12.43	12.43	12.45	12.46	12.46	12.47	12.47
10°S	13.04	12.95	12.82	12.69	12.58	12.44	12.26	12.15	12.05	11.96	11.92	11.89
20°S	13.66	13.49	13.26	12.97	12.75	12.44	12.11	11.85	11.63	11.45	11.33	11.31
30°S	14.40	14.12	13.74	13.30	12.94	12.48	11.94	11.52	11.17	10.87	10.69	10.62
40°S	15.35	14.94	14.39	13.74	13.21	12.53	11.76	11.15	10.61	10.19	9.89	9.81
50°S	16.79	16.14	15.30	14.37	13.58	12.63	11.52	10.65	9.88	9.23	8.81	8.68
60°S	19.71	18.36	16.87	15.38	14.22	12.81	11.19	9.90	8.72	7.69	7.00	6.77

Latitude	July		August		September		October		November		December	
	7	22	7	22	7	22	7	22	7	22	7	22
70°N	24.00	24.00	21.89	18.80	15.52	13.24	11.09	8.93	6.69	4.05	2.22	1.92
60°N	19.90	18.70	17.32	15.91	14.22	12.85	11.50	10.18	8.94	7.84	7.06	6.78
50°N	16.86	16.33	15.57	14.70	13.59	12.67	11.73	10.85	10.01	9.32	8.84	8.68
40°N	15.40	15.05	14.56	13.98	13.21	12.56	11.91	11.28	10.71	10.24	9.92	9.80
30°N	14.42	14.20	13.87	13.46	12.93	12.49	12.06	11.62	11.24	10.92	10.69	10.62
20°N	13.67	13.53	13.33	13.07	12.73	12.46	12.17	11.90	11.68	11.48	11.36	11.29
10°N	13.04	12.97	12.86	12.75	12.58	12.45	12.31	12.18	12.06	11.98	11.92	11.91
0°	12.47	12.46	12.45	12.44	12.45	12.43	12.44	12.45	12.46	12.47	12.84	12.48
10°S	11.92	11.97	12.05	12.16	12.31	12.45	12.58	12.73	12.86	12.97	13.04	13.08
20°S	11.34	11.46	11.66	11.87	12.18	12.46	12.75	13.04	13.29	13.53	13.68	13.73
30°S	10.71	10.91	11.19	11.57	12.08	12.51	12.97	13.41	13.83	14.18	14.44	14.51
40°S	9.92	10.22	10.66	11.20	11.92	12.57	13.24	13.90	14.51	15.04	15.41	15.53
50°S	8.85	9.29	9.95	10.73	11.77	12.69	13.63	14.58	15.50	16.30	16.86	17.07
60°S	7.07	7.80	8.83	10.01	11.55	12.89	14.28	15.72	17.20	18.65	19.95	20.51

Table 4. Photoperiod in hours with a minimum intensity of 2 foot candles (21.5 lux).

Cuadro 4. Fotoperíodo en horas con una intensidad mínima de 2 bujías (21.5 lux).

Quadro 4. Fotoperíodo em horas com uma intensidade mínima de 2 velas (21.5 lux).

Latitude	January		February		March		April		May		June	
	7	22	7	22	7	22	7	22	7	22	7	22
70°N	3.04	5.23	7.56	9.77	11.49	13.68	16.53	19.64	22.59	24.00	24.00	24.00
60°N	7.45	8.30	9.42	10.70	11.76	13.12	14.82	16.27	17.75	19.20	20.46	21.04
50°N	9.10	9.63	10.35	11.20	11.93	12.87	14.02	14.95	15.84	16.60	17.11	17.28
40°N	10.11	10.46	10.96	11.56	12.07	12.73	13.52	14.16	14.76	15.26	15.58	15.69
30°N	10.86	11.10	11.43	11.83	12.18	12.64	13.18	13.63	14.02	14.36	14.58	14.64
20°N	11.47	11.62	11.83	12.08	12.30	12.57	12.92	13.20	13.45	13.66	13.80	13.84
10°N	12.04	12.11	11.20	12.31	12.41	12.54	12.72	12.85	12.98	13.09	13.15	13.17
0°	12.58	12.57	12.55	12.54	12.53	12.53	12.53	12.54	12.57	12.57	12.58	12.58
10°S	13.14	13.05	12.92	12.79	12.68	12.54	12.36	12.25	12.15	12.06	12.03	12.00
20°S	13.77	13.60	13.37	13.08	12.85	12.55	12.21	11.96	11.74	11.56	11.45	11.42
30°S	14.53	14.25	13.86	13.42	13.06	12.59	12.06	11.64	11.29	10.99	10.81	10.75
40°S	15.50	15.08	14.52	13.87	13.34	12.66	11.88	11.28	10.75	10.33	10.04	9.95
50°S	16.99	16.33	15.47	14.53	13.74	12.78	11.67	10.80	10.04	9.40	8.99	8.86
60°S	20.11	18.66	17.12	15.61	14.42	13.00	11.39	10.11	8.94	7.94	7.26	7.04

Latitude	July		August		September		October		November		December	
	7	22	7	22	7	22	7	22	7	22	7	22
70°N	24.00	24.00	22.45	19.27	15.84	13.53	11.38	9.24	7.07	4.63	2.89	2.50
60°N	20.32	19.03	17.59	16.14	14.43	13.04	11.69	10.38	9.16	8.08	7.32	7.05
50°N	17.06	16.52	15.75	14.86	13.74	12.82	11.88	11.00	10.17	9.49	9.02	8.86
40°N	15.56	15.20	14.70	14.11	13.34	12.68	12.03	11.41	10.85	10.38	10.06	9.95
30°N	14.55	14.32	13.99	13.58	13.05	12.61	12.17	11.73	11.36	11.04	10.81	10.75
20°N	13.78	13.64	13.44	13.18	12.83	12.57	12.28	12.01	11.79	11.59	11.47	11.41
10°N	13.15	13.08	12.97	12.85	12.68	12.54	12.41	12.28	12.16	12.08	12.03	12.02
0°	12.58	12.57	12.55	12.54	12.54	12.52	12.53	12.54	12.57	12.57	12.59	12.59
10°S	12.03	12.08	12.15	12.26	12.41	12.54	12.68	12.83	12.97	13.08	13.15	13.19
20°S	11.46	11.57	11.77	11.98	12.28	12.57	12.86	13.15	13.40	13.64	13.79	13.84
30°S	10.83	11.03	11.31	11.68	12.19	12.62	13.08	13.53	13.95	14.31	14.57	14.64
40°S	10.06	10.36	10.80	11.33	12.05	12.70	13.37	14.03	14.65	15.18	15.56	15.69
50°S	9.03	9.47	10.11	10.89	11.92	12.84	13.79	14.75	15.67	16.49	17.07	17.28
60°S	7.34	8.05	9.05	10.22	11.74	13.09	14.48	15.95	17.47	18.98	20.37	21.01

Table 5. Photoperiod in hours with a minimum intensity of 1 foot candle (10.8 lux).

Cuadro 5. **Fotoperíodo en horas con una intensidad mínima de 1 bujía (10.8 lux).**

Quadro 5. Fotoperíodo em horas com uma intensidade mínima de uma vela (10.8 lux).

Latitude	January		February		March		April		May		June	
	7	22	7	22	7	22	7	22	7	22	7	22
70°N	3.59	5.62	7.84	10.01	11.71	13.90	16.79	20.03	22.98	24.00	24.00	24.00
60°N	7.65	8.48	9.59	10.85	11.91	13.27	14.98	16.45	17.96	19.46	20.79	21.43
50°N	9.23	9.76	10.48	11.32	12.05	12.98	14.14	15.07	15.98	16.75	17.26	17.45
40°N	10.22	10.56	11.07	11.66	12.16	12.83	13.62	14.27	14.87	15.37	15.70	15.81
30°N	10.96	11.19	11.52	11.92	12.26	12.73	13.27	13.72	14.11	14.45	14.68	14.74
20°N	11.56	11.71	11.91	12.16	12.38	12.64	13.00	13.28	13.54	13.75	13.89	13.93
10°N	12.12	12.19	12.28	12.39	12.49	12.62	12.80	12.93	13.06	13.17	13.24	13.25
0°	12.66	12.64	12.63	12.62	12.61	12.60	12.60	12.62	12.64	12.64	12.66	12.66
10°S	13.22	13.13	13.00	12.87	12.75	12.62	12.44	12.33	12.23	12.14	12.11	12.09
20°S	13.86	13.68	13.45	13.16	12.93	12.63	12.29	12.04	11.82	11.65	11.53	11.51
30°S	14.63	14.34	13.96	13.50	13.14	12.68	12.14	11.73	11.38	11.08	10.91	10.85
40°S	15.62	15.19	14.63	13.97	13.44	12.76	11.98	11.38	10.85	10.44	10.15	10.06
50°S	17.15	16.48	15.60	14.65	13.86	12.90	11.78	10.92	10.17	9.54	9.13	9.00
60°S	20.43	18.90	17.32	15.78	14.58	13.16	11.54	10.27	9.12	8.13	7.47	7.25

Latitude	July		August		September		October		November		December	
	7	22	7	22	7	22	7	22	7	22	7	22
70°N	24.00	24.00	22.88	19.64	16.09	13.76	11.61	9.49	7.37	5.09	3.41	2.95
60°N	20.64	19.28	17.80	16.31	14.59	13.19	11.84	10.54	9.33	8.27	7.52	7.26
50°N	17.21	16.67	15.88	14.99	13.86	12.93	12.00	11.12	10.30	9.62	9.16	8.99
40°N	15.68	15.31	14.81	14.22	13.44	12.78	12.13	11.51	10.95	10.49	10.17	10.06
30°N	14.65	14.42	14.08	13.67	13.14	12.69	12.26	11.82	11.45	11.13	10.91	10.84
20°N	13.87	13.73	13.52	13.26	12.91	12.64	12.36	12.09	11.87	11.68	11.56	11.49
10°N	13.24	13.16	13.05	12.93	12.75	12.62	12.49	12.35	12.24	12.16	12.11	12.10
0°	12.66	12.64	12.63	12.62	12.62	12.60	12.61	12.62	12.64	12.65	12.67	12.67
10°S	12.11	12.16	12.23	12.34	12.49	12.62	12.75	12.91	13.05	13.16	13.24	13.27
20°S	11.54	11.66	11.85	12.06	12.36	12.64	12.94	13.24	13.49	13.73	13.88	13.93
30°S	10.92	11.12	11.40	11.77	12.28	12.71	13.17	13.62	14.05	14.40	14.66	14.74
40°S	10.17	10.47	10.90	11.43	12.15	12.80	13.47	14.13	14.76	15.29	15.68	15.81
50°S	9.16	9.60	10.24	11.01	12.03	12.96	13.91	14.87	15.80	16.64	17.23	17.44
60°S	7.54	8.23	9.23	10.38	11.89	13.24	14.64	16.13	17.67	19.23	20.70	21.39

Table 6. Times of sunrise and sunset, hours and minutes of sunlight, and hours (and decimals of hours) of sunlight.

Cuadro 6. Hora exacta de salida y puesta de sol, horas y minutos de luz solar y horas (y decimales de horas) de luz solar.

Quadro 6. Hora exata de saída e pôr do sol, horas e minutos de luz solar e horas (e décimos de horas) de luz solar.

Latitude	January 7				January 22				February 7			
	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC
70°N	*	*	0	0	1042	1343	3:01	3.02	0915	1515	6:00	6.00
60°N	0857	1517	6:20	6.33	0834	1551	7:17	7.28	0800	1630	8:30	8.50
50°N	0757	1617	8:20	8.33	0745	1639	8:54	8.90	0725	1704	9:39	9.65
40°N	0722	1652	9:30	9.50	0716	1708	9:52	9.87	0703	1726	10:23	10.38
30°N	0657	1717	10:20	10.33	0655	1729	10:34	10.57	0647	1742	10:55	10.92
20°N	0637	1736	10:59	10.98	0638	1746	11:08	11.13	0633	1755	11:22	11.37
10°N	0619	1754	11:35	11.58	0622	1801	11:39	11.65	0622	1807	11:45	11.75
0°	0603	1810	12:07	12.12	0608	1815	12:07	12.12	0611	1818	12:07	12.12
10°S	0546	1827	12:41	12.68	0554	1830	12:36	12.60	0600	1829	12:29	12.48
20°S	0528	1845	13:17	13.28	0538	1845	13:07	13.12	0547	1841	12:54	12.90
30°S	0508	1906	13:58	13.97	0520	1903	13:43	13.72	0534	1854	13:20	13.33
40°S	0441	1932	14:51	14.85	0458	1925	14:27	14.45	0516	1912	13:56	13.93
50°S	0403	2010	16:07	16.12	0426	1957	15:31	15.52	0452	1935	14:43	14.72
60°S	0255	2117	18:22	18.37	0331	2051	17:20	17.33	0412	2014	16:02	16.03

* No sunrise.

Latitude	February 22				March 7				March 22			
	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC
70°N	0801	1628	8:27	8.45	0705	1720	10:17	10.28	0556	1821	12:25	12.42
60°N	0719	1709	9:50	9.83	0644	1739	10:55	10.92	0600	1816	12:16	12.27
50°N	0658	1730	10:32	10.53	0634	1750	11:16	11.27	0601	1814	12:13	12.22
40°N	0644	1744	11:00	11.00	0626	1757	11:31	11.52	0602	1813	12:11	12.18
30°N	0634	1754	11:20	11.33	0621	1803	11:42	11.70	0603	1812	12:09	12.15
20°N	0625	1802	11:37	11.62	0616	1807	11:51	11.85	0604	1811	12:07	12.12
10°N	0617	1810	11:53	11.88	0612	1811	11:59	11.98	0604	1811	12:07	12.12
0°	0610	1817	12:07	12.12	0608	1815	12:07	12.12	0604	1810	12:06	12.10
10°S	0603	1824	12:21	12.35	0604	1819	12:15	12.25	0604	1810	12:06	12.10
20°S	0555	1832	12:37	12.62	0559	1823	12:24	12.40	0604	1810	12:06	12.10
30°S	0546	1841	12:55	12.92	0554	1828	12:34	12.57	0604	1810	12:06	12.10
40°S	0534	1852	13:18	13.30	0548	1834	12:46	12.77	0604	1810	12:06	12.10
50°S	0518	1908	13:50	13.83	0539	1843	13:04	13.07	0603	1811	12:08	12.13
60°S	0453	1932	14:39	14.65	0524	1857	13:33	13.55	0602	1811	12:09	12.15

Table 6 (continued).

Latitude	April 7				April 22				May 7			
	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC
70°N	0431	1935	15:04	15.07	0316	2044	17:28	17.47	0148	2211	20:23	20.38
60°N	0505	1900	13:55	13.92	0421	1937	15:16	15.27	0340	2015	16:35	16.58
50°N	0522	1842	13:20	13.33	0452	1906	14:14	14.23	0425	1929	15:04	15.07
40°N	0534	1831	12:57	12.95	0511	1846	13:35	13.58	0452	1901	14:09	14.15
30°N	0542	1823	12:41	12.68	0525	1832	13:07	13.12	0512	1842	13:30	13.50
20°N	0548	1816	12:28	12.47	0536	1821	12:45	12.75	0527	1826	12:59	12.98
10°N	0554	1810	12:16	12.27	0546	1811	12:25	12.42	0541	1813	12:32	12.53
0°	0559	1805	12:06	12.10	0555	1802	12:07	12.12	0553	1800	12:07	12.12
10°S	0604	1800	11:56	11.93	0604	1753	11:49	11.82	0605	1748	11:43	11.72
20°S	0609	1755	11:46	11.77	0613	1743	11:30	11.50	0618	1734	11:16	11.27
30°S	0615	1749	11:34	11.57	0624	1732	11:08	11.13	0633	1719	10:46	10.77
40°S	0622	1742	11:20	11.33	0637	1720	10:43	10.72	0651	1701	10:10	10.17
50°S	0631	1732	11:01	11.02	0654	1702	10:08	10.13	0716	1636	9:20	9.33
60°S	0645	1717	10:32	10.53	0721	1634	9:13	9.22	0757	1555	7:58	7.97

Latitude	May 22				June 7				June 22			
	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC
70°N	**	**	24:00	24.00	**	**	24:00	24.00	**	**	24:00	24.00
60°N	0305	2049	17:44	17.73	0242	2116	18:34	18.57	0236	2128	18:52	18.87
50°N	0404	1950	15:46	15.77	0352	2006	16:14	16.23	0351	2013	16:22	16.37
40°N	0438	1915	14:37	14.62	0431	1926	14:55	14.92	0431	1932	15:01	15.02
30°N	0502	1851	13:49	13.82	0458	1859	14:01	14.02	0459	1904	14:05	14.08
20°N	0521	1832	13:11	13.18	0520	1838	13:18	13.30	0522	1842	13:20	13.33
10°N	0538	1816	12:38	12.63	0538	1819	12:41	12.68	0541	1823	12:42	12.70
0°	0553	1800	12:07	12.12	0555	1802	12:07	12.12	0558	1805	12:07	12.12
10°S	0608	1745	11:37	11.62	0612	1746	11:34	11.57	0616	1748	11:32	11.53
20°S	0624	1729	11:05	11.08	0630	1728	10:58	10.97	0634	1730	10:56	10.93
30°S	0642	1711	10:29	10.48	0650	1707	10:17	10.28	0656	1708	10:12	10.20
40°S	0705	1648	9:43	9.72	0716	1641	9:25	9.42	0722	1642	9:20	9.33
50°S	0737	1616	8:39	8.65	0752	1605	8:13	8.22	0800	1604	8:04	8.07
60°S	0830	1523	6:53	6.88	0855	1502	6:07	6.12	0906	1458	5:52	5.87

** No sunset.

Table 6 (continued).

Latitude	July 7				July 22				August 7			
	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC
70°N	**	**	24:00	24.00	**	**	24:00	24.00	0202	2204	20:02	20.03
60°N	0249	2119	18:30	18.50	0317	2054	17:37	17.62	0352	2018	16:24	16.40
50°N	0359	2010	16:11	16.18	0415	1957	15:42	15.70	0436	1935	14:59	14.98
40°N	0438	1931	14:53	14.88	0449	1923	14:34	14.57	0503	1909	14:06	14.10
30°N	0505	1905	14:00	14.00	0513	1900	13:47	13.68	0522	1850	13:28	13.47
20°N	0526	1843	13:17	13.28	0532	1841	13:09	13.15	0537	1835	12:58	12.97
10°N	0544	1825	12:41	12.68	0548	1825	12:37	12.62	0550	1821	12:31	12.52
0°	0601	1808	12:07	12.12	0603	1810	12:07	12.12	0602	1809	12:07	12.12
10°S	0618	1752	11:34	11.57	0618	1755	11:37	11.62	0614	1757	11:43	11.72
20°S	0636	1734	10:58	10.97	0634	1739	11:05	11.08	0627	1745	11:18	11.30
30°S	0656	1714	10:18	10.30	0651	1722	10:31	10.52	0642	1730	10:48	10.80
40°S	0721	1648	8:27	8.45	0714	1659	9:45	9.75	0700	1713	10:13	10.22
50°S	0757	1613	8:16	8.27	0745	1628	8:43	8.72	0724	1648	9:24	9.40
60°S	0859	1511	6:12	6.20	0837	1537	7:00	7.00	0803	1609	8:06	8.10

** No sunset.

Latitude	August 22				September 7				September 22			
	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC
70°N	0324	2038	17:14	17.23	0443	1910	14:27	14.25	0543	1800	12:17	12.28
60°N	0428	1937	15:09	15.15	0511	1843	13:32	13.53	0546	1758	12:12	12.20
50°N	0458	1907	14:09	14.15	0525	1830	13:05	13.08	0547	1757	12:10	12.17
40°N	0517	1849	13:32	13.53	0534	1821	12:47	12.78	0548	1756	12:07	12.12
30°N	0531	1835	13:04	13.07	0541	1814	12:33	12.55	0549	1756	12:07	12.12
20°N	0541	1824	12:43	12.72	0546	1809	12:23	12.38	0549	1756	12:07	12.12
10°N	0551	1815	12:24	12.40	0550	1805	12:15	12.25	0549	1756	12:07	12.12
0°	0600	1806	12:06	12.10	0554	1801	12:07	12.12	0549	1756	12:07	12.12
10°S	0608	1758	11:50	11.83	0558	1757	11:59	11.98	0549	1756	12:07	12.12
20°S	0618	1749	11:31	11.52	0603	1753	11:50	11.83	0549	1756	12:07	12.12
30°S	0628	1739	11:11	11.18	0607	1749	11:42	11.70	0549	1757	12:08	12.13
40°S	0640	1726	10:46	10.77	0613	1743	11:30	11.50	0548	1757	12:09	12.15
50°S	0657	1710	10:13	10.22	0620	1736	11:16	11.27	0547	1758	12:11	12.18
60°S	0724	1644	9:20	9.33	0631	1725	10:54	10.90	0546	1800	12:14	12.23

Table 6 (continued).

Latitude	October 7				October 22				November 7			
	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC
70°N	0643	1651	10:08	10.13	0747	1540	7:53	7.88	0901	1426	5:25	5.42
60°N	0622	1713	10:51	10.85	0659	1629	9:30	9.50	0737	1550	8:13	8.22
50°N	0610	1724	11:14	11.23	0634	1654	10:20	10.33	0659	1628	9:29	9.48
40°N	0603	1732	11:29	11.48	0619	1710	10:51	10.85	0636	1652	10:16	10.27
30°N	0557	1738	11:41	11.68	0607	1721	11:14	11.23	0618	1709	10:51	10.85
20°N	0553	1742	11:49	11.82	0558	1731	11:33	11.55	0604	1723	11:19	11.32
10°N	0548	1747	11:59	11.98	0549	1740	11:51	11.85	0552	1735	11:43	11.72
0°	0544	1751	12:07	12.12	0541	1748	12:07	12.12	0540	1747	12:07	12.12
10°S	0540	1755	12:15	12.25	0533	1756	12:23	12.38	0528	1759	12:31	12.52
20°S	0536	1800	12:24	12.40	0524	1805	12:41	12.68	0516	1812	12:56	12.93
30°S	0530	1805	12:35	12.58	0514	1815	13:01	13.02	0501	1827	13:26	13.43
40°S	0524	1812	12:48	12.80	0501	1828	13:27	13.45	0443	1846	14:03	14.05
50°S	0515	1822	13:07	13.12	0444	1846	14:02	14.03	0417	1912	14:55	14.92
60°S	0500	1836	13:36	13.60	0416	1914	14:58	14.97	0335	1954	16:19	16.32

Latitude	November 22				December 7				December 22			
	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC	SUN-RISE	SUN-SET	SUN HR-MIN	SUN HR-DEC
70°N	1043	1249	2:06	2.10	*	*	0	0	*	*	0	0
60°N	0815	1517	7:02	7.03	0846	1457	6:11	6.18	0902	1455	5:53	5.88
50°N	0723	1608	8:45	8.75	0744	1559	8:15	8.25	0756	1601	8:42	8.70
40°N	0653	1639	9:46	9.77	0708	1635	9:27	9.45	0719	1638	9:46	9.77
30°N	0630	1701	10:31	10.52	0643	1700	10:17	10.28	0652	1705	10:34	10.57
20°N	0613	1719	11:06	11.10	0622	1721	10:59	10.98	0631	1726	11:14	11.23
10°N	0557	1735	11:38	11.63	0604	1738	11:34	11.57	0612	1745	11:33	11.55
0°	0542	1750	12:08	12.13	0548	1755	12:07	12.12	0555	1802	12:07	12.12
10°S	0528	1805	12:37	12.62	0531	1812	12:41	12.68	0537	1820	12:43	12.72
20°S	0512	1821	13:09	13.15	0513	1830	13:17	13.28	0518	1839	13:21	13.35
30°S	0453	1839	13:46	13.77	0451	1852	14:01	14.02	0456	1901	14:05	14.08
40°S	0430	1903	14:33	14.55	0425	1919	14:54	14.90	0428	1929	15:01	15.02
50°S	0357	1937	15:40	15.67	0346	1957	16:11	16.18	0347	2010	16:23	16.38
60°S	0300	2034	17:34	17.57	0236	2108	18:32	18.53	0233	2125	18:52	18.87

* No sunrise.

RESUMEN

La sensibilidad al fotoperiodo de cultivos ha mostrado tener un efecto notable en el desarrollo y en su producción. El valor de la insensibilidad al largo del día demuestra ser de amplia adaptación para las variedades nuevas de arroz y de trigo; estas variedades se adaptan a varias latitudes. Actualmente, forman parte fundamental del conjunto tecnológico que se ha denominado la "Revolución Verde".

Esta publicación presenta los datos de la duración natural del día, con una intensidad mínima de 10, 5, 2 y 1 bujía (107.6, 53.8, 21.5 y 10.8 lux, respectivamente). Las figuras y cuadros incluyen también los datos para cada 15 días durante todo el año y para cada latitud, desde los 70° N a los 60° S. La información fue presentada por primera vez en publicación *Journal of Agronomy* (1); en la presente publicación se ha aumentado el tamaño de las gráficas y se han incluido los datos originales para dar al investigador una idea más precisa de las condiciones que existen en su localidad. Esto ayuda en la interpretación de los resultados obtenidos en el campo y orientarle en la planeación de proyectos que pretenden resolver el problema de sensibilidad al fotoperiodo.

RESUMO

A sensibilidade ao fotoperiodo tem mostrado possuir um efeito notável no desenvolvimento da planta e na sua produção. O valor da insensibilidade ao comprimento do dia demonstra ser de grande valor para as novas variedades de arroz e de trigo; estas variedades se adaptam a várias latitudes e atualmente, são parte fundamental do conjunto tecnológico denominado "Revolução Verde".

Esta publicação apresenta os dados da duração natural do dia, com uma intensidade mínima de 10, 5, 2 e 1 vela (107.6, 53.8, 21.5 e 10.8 lux, respectivamente). As figuras e quadros encluem também os dados quinzenais durante o ano e para cada latitude, desde 70°N, até 60°S. A informação foi apresentada pela primeira vez em publicação no "Journal of Agronomy (1); na presente publicação se aumentou o tamanho dos gráficos e se incluiu os dados originais para dar ao investigador uma ideia mais precisa das condições existentes em sua localidade. Na interpretação dos resultados obtidos no campo e orientá-lo no planejamento de trabalhos que pretendem resolver o problema da sensibilidade ao fotoperiodo.

REFERENCES

1. Francis, C. A. 1970. Effective daylengths for the study of photoperiod sensitive reactions in plants. *Agron. J.* 62: 790-792.
2. Francis, C. A., D. Sarria V., D. D. Harpstead, and C. Cassalet D. 1970. Identification of photoperiod insensitive strains of maize (*Zea mays* L.). II. Field tests in the tropics with artificial lights. *Crop Sci.* 10:465-468.
3. Hodgman, C. D. (ed.) 1958. *Handbook of Chemistry and Physics*, 40th Edition. Chemical Rubber Publishing Co., p. 2,743.
4. Kähler, K. 1927. *Met. Zs.* 44:212. (As cited in M. Minnaert. 1954. *The Nature of Light and Colour in the Open Air*. Dover Publishing, Inc., New York, p. 81).
5. U.S. Naval Observatory. 1963. *The Nautical Almanac*, 1965. U.S. Government Printing Office, Washington, D.C.