LIGHT EFFECTS ON PLANTS

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What we call light comes to us from the sun and is the product of countless nuclear reactions occurring on the sun's surface. Each second the sun emits energy equivalent to 1 million times all of the known and used supplies of the earth's coal, natural gas and petroleum. The energy produced by the sun passes through space as electromagnetic radiation of varying wavelengths and the spectrum of much of it is indicated in Figure 1. In relation to the total energy spectrum, the visible portion is quite small. Because of the relative size of the earth and its distance from the sun we receive only a small proportion of the energy emitted by the sun; two very obvious ways in which it is utilized is in heating our atmosphere and in stimulating and controlling plant growth.

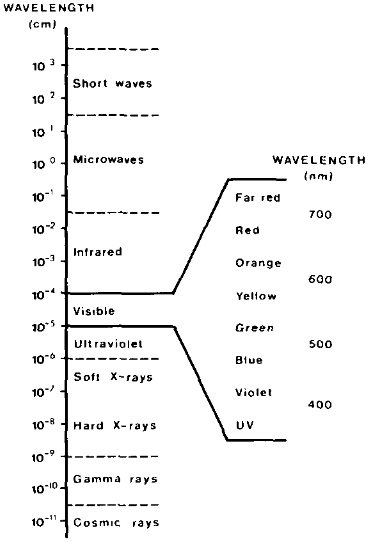

Figure 1. Electromagnetic radiation spectrum.

By far the most important light reaction of plants is photosynthesis. The green coloring matter in plants, chlorophyll, absorbs two colors of light (Figure 2) and through the absorption of radiant energy enables the plant to take carbon dioxide from the air and water from the soil and convert them, together with absorbed minerals, into all of its many parts. The light that's absorbed is in the red and blue parts of the spectrum, and the more light that's provided to the plant, the more it will use in growth. In general, photosynthesis requires more than 100 foot-candles of light before anything happens, and an increasing response is observed up to about 10,000 foot-candles. It is impossible to overemphasize the importance of photosynthesis. It is the starting point for all plant growth and, since all animal and marine growth is ultimately dependent on plants, photosynthesis is the key photo-reaction for all life on our plants.

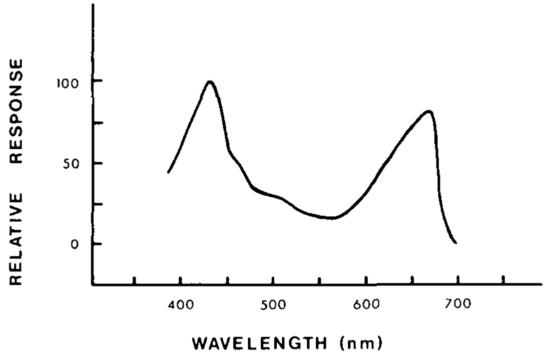

Figure 2. Relative photosynthesis response to light of different qualities.

In addition to photosynthesis, there is a second photoreaction in plants, called photoperiodism. It differs from photosynthesis in several ways and is frequently the reason plants behave the way they do. While the pigment or receptor for photosynthesis is chlorophyll, and is green, and is present in large amounts in almost all plants, the pigment or receptor for photoperiodism is called phytochrome, is blue, and occurs in very small amounts in all plants (Table 1). As indicated above, photosynthesis requires light intensities of between 100 and 10,000 f.c. before carbon dioxide and water can be converted into sugars in the plant. Photoperiodism, on the other hand, only requires light intensities of up to 5 or 10 f.c. Thus, the maximum response of this light system is produced by about 1/1000th the amount of light that saturates the photosynthetic system. Interestingly, on very clear, bright nights, the intensity of moonlight may be just enough to cause at least a partial response. Both photosystems are similar in that red light is a major part of the effective spectrum.

But what does photoperiodism do — why is it important? Table 2 indicates some of the processes in many plants that are controlled by phytochrome. It is obvious that activation of the photoreceptor pigment, phytochrome, affects plants during their very earliest stages, like germination and hypocotyl hook opening, through the vegetative and growing stages, and even affects aspects of the termination of growth, such as initiation of dormancy, leaf abscission, coloration of fruit, and onset of the reproductive phase itself, the initiation of flowering. An important aspect of this is that not all plants necessarily have the same process controlled in the same way. For example, although the germination of seeds of some plants is sensitive to light, many others are not. Bud dormancy is another process which is controlled by different systems in different plants, and so are others on the list.

Table 1. Comparison of photosynthetic and photoperiodic light systems.

	PHOTOSYNTHESIS	PHOTOPERIODISM
Photoreceptor	Chlorophyll	Phytochrome
Color of photoreceptor	Green	Blue
Amount of photoreceptor present in plants	Large	Small
Effective wavelengths	Red and blue	Red and far-red
Light intensities required	100-10,000 f.c.	0.01 - 10 f.c.
Nature of mechanism	Quantitative	Trigger or threshold
Action	Converts CO_2 and H_2O to sugars	Regulates time measuring ability

Table 2. Some phytochrome-mediated photoresponses.

1. Elongation (leaf, petiole, stem)
2. Hypocotyl hook unfolding
3. Unfolding of grass leaf
4. Sex expression
5. Bud dormancy
6. Root development
7. Rhizome formation
8. Bulb formation
9. Leaf abscission
10. Epinasty
11. Succulency
12. Enlargement of cotyledons
13. Formation of leaf primordia
14. Seed germination
15. Flower induction
16. Differentiation of primary leaves

The name of this light reaction, photoperiodism, implies an ability to measure, or be influenced by, the length of the exposure to light. This is again different from the photosynthetic light system, in which the amount of light, rather than the length of the light period, is measured. If the list of processes in Table 2 is examined closely, it can be observed that all of them are usually influenced by the time of the year, or the time of the day. Thus, any seasonal response of plants which is sensitive to light, probably involves the phytochrome system and this change in the seasons is detected by measuring the change in the daylength or, in reality, the change in the nightlength. The length of the night has been identified as the crucial factor because, although interruption of the light period with a brief period of darkness does not alter the response, interrupting the long dark period with light for even as short a time as a few seconds or minutes can change the response dramatically. Thus, the shortening nights of spring, or the lengthening nights of autumn are the triggers which alter the growth and development of responsive plants, and some plants can detect differences in nightlength as small as 20 minutes.

Of the many phytochrome-controlled photoperiodic responses indicated in Table 2. the most important is probably flowering. Many, though not all, plants have a definite flowering season and, in the majority of cases, the plants are reacting to changes in the length of the dark period rather than to temperature, or moisture availability, etc. Some plants are known as longday plants, and others are shortday, and the responses of barley and *Chrysanthemum*, good examples of the two types, are indicated in Figure 3. It is obvious that barley, a longday plant, flowers very much more quickly in long, than in short days, whereas *Chrysanthemum*, a shortday plant, behaves exactly the opposite. Not all plants are responsive to daylength in the control of flowering; some, like tomatoes, are called day neutral and flower when they reach a certain stage in development. Some plants also have a temperature requirement mixed in with their light requirement.

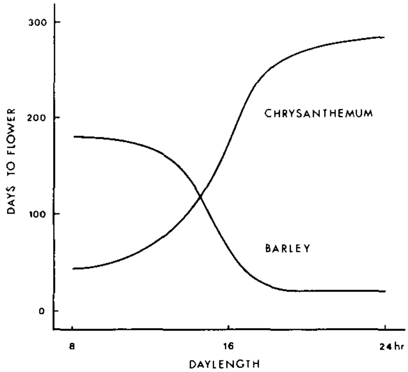

Figure 3. Effect of daylength on the time taken by *Chrysanthemum* and barley plants to flower.

As indicated in Figure 3, *Chrysanthemum* flowers when exposed to long nights. So, if it is desirable to keep *Chrysanthemum* vegetative in autumn, supplementary lighting can be used to shorten the night. An important aspect is that the amount of light required is very low, no more than 5 to 10 foot-candles, well below the energy level necessary for photosynthesis. In this way we can keep *Chrysanthemums* vegetative in winter and, by lengthening the nights during summer, we can make them flower completely out of season. These responses are illustrated in Figure 4. The light and dark periods (which add up to a 24 hr day) are indicated above the plants, and the short-day-requiring *Xanthium* behaves opposite to the long-day-requiring *Hyoscyamus*. In addition to this, Figure 4 also shows something else. If the short-day *Xanthium* is exposed to long nights (the first column), it flowers. However, if those long nights are interrupted by a very brief flash of low intensity light (the last column) flowering is not induced, and the plant stays vegetative. Just the opposite happens with the long-day *Hyoscyamus*. It requires long days and thus doesn't flower when the night is long. If that long night is interrupted by a flash of light, even though the night is essentially the same length, *Hyoscyamus* will flower.

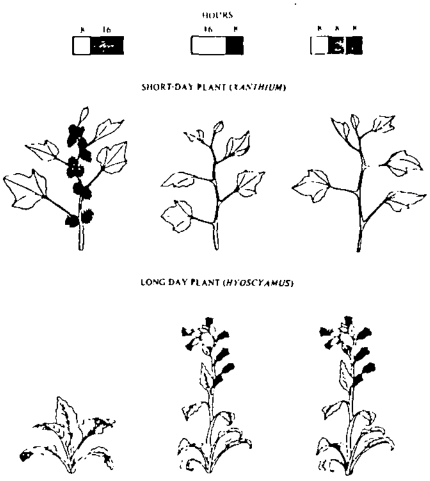

Figure 4. Photoperiodic control of flowering. Bars above plants indicate light and dark periods in a 24 hr. day.

These results and many others have increased our level of scientific understanding of how and why plants grow and behave the way they do. In addition, they have given us a second way to commercially control the behavior of plants through altering their light environment. Not only can we use low intensity light to extend the daylength, or cover plants with shades if it is desirable to shorten the daylength, but it is also possible to interrupt the long nights of winter and produce summer-type responses.

In fact, that's at least part of what plant physiology is all about, a study of the normal growth and development of plants, with the eventual aim of understanding it well enough to be able to control it, to maximize the benefits for mankind. One of the most important plant processes to control, in fact, is flowering. If there were ways to promote it or delay it in a wide range of plants, and particularly in crops, food production would be facilitated. Control in this respect is not limited only to the production of ornamental flowering plants, but also to the ability to prevent crops from going to seed, or making other crops flower sooner or more uniformly, or all year round, etc.

But flowering is not the only part of the photoperiodic system it would be useful to be able to control. For instance, many woody plants or trees are stimulated in their growth as the daylength is lengthened. An example of the effect of photoperiod on the growth of Douglas fir is illustrated in Table 3. As the daylength was increased, branch and elongation growth were all stimulated. The table also shows that if a 12 hr night period was interrupted with a low intensity light break of 1 hr, the seedlings grew as if they were in a 16 to 20 hr day. Figure 5 illustrates this more clearly.

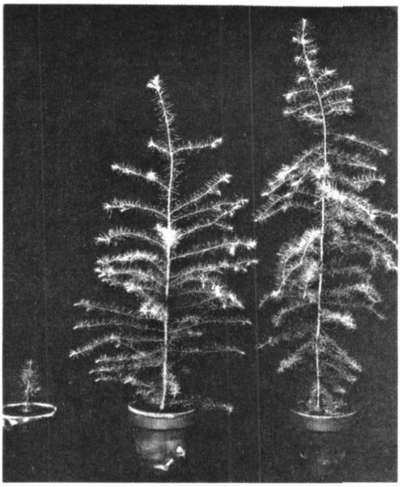

Figure 5. Growth of Douglas fir after 12 months on photoperiods of 12 hr, 12 hr plus 1 hr interruption in the middle of the dark period, and 20 hr, from left to right.

Table 3. Effect of photoperiod on growth of Douglas-fir (adapted from Downs, 1962).

	Length			
Photoperiod (Hours)	Main Axis (Centimeters)	Branches (Centimeters)	Total Growth (Centimeters)	Branches (Number)
10	8.4	0.7	9.2	1.9
12	9.4	2.8	12.2	3.2
14	19.7	9.6	29.3	3.8
16	38.9	91.2	140.4	16.0
20	47.9	227.1	274.9	29.5
24	52.9	190.3	243.2	24.2
12 + 1*	41.7	176.0	217.7	23.0
LSD (5%)	7.7	77.0	81.5	8.3

* A 1-hour interruption near the middle of the dark period, using an illuminance of 40 foot candles from incandescent-filament lamps.

Douglas fir is not the only tree species to respond. A large number do, for example, yellow poplar, loblolly pine, Scots pine, to name just a few. If tree seedlings could be irradiated during the winter nights for short periods with low-intensity effective wavelengths, it might be possible to effectively enhance tree seedling growth, provided, of course, that the temperatures were not too low.

In addition to flowering and woody tree growth, runner production in some strawberry cultivars, root growth and development in some root crops, like potatoes and onions, etc., are controlled by the phytochrome-photoperiodic system. The sex of cucurbit flowers is also strongly influenced by photoperiod.

In spite of the many ways in which plant growth and development might be controlled through a night interruption, a most important consideration is the cost. The price of setting up fluorescent or incandescent lights for night interruptions is high, partly because only a small proportion of the light produced by these sources is of the right wavelengths. Another reason for the high expense is that the light intensity from normal light sources decreases very greatly with distance and, as a consequence, many light fittings are needed.

There is one kind of light source, however, that's quite different from incandescent, or fluorescent sources, and that's a laser (*l*ight *a*mplification by *s*timulated *e*mission of *r*adiation). Two of the chief characteristics of lasers are that the emission is coherent, which means that it can travel quite long distances without decreasing in intensity to any great degree, and also that it's monochromatic (or light of a very narrow wavelength).

At this point it seems reasonable to ask whether, if the laser light source differs in any way from other kinds of light sources, will it cause the same effects, and, in particular, whether it will activate phytochrome, the photoperiod pigment? Figure 6 demonstrates the ability of a Helium-Neon laser (which produces red light of 632.8 nM) to inhibit flowering through an interruption of the long night of Japanese Morning Glory (*Pharbitis*).

The results are of duplicate experiments and demonstrate that 100 secs. night interruption with this laser almost completely inhibited flowering of these *Pharbitis* plants. And what about distance? How far can the light go and still be effective? The results in Figure 7 are also with *Pharbitis* but with a less powerful laser. In this experiment 1000 secs. night interruption eliminated flowering, and these values were obtained at a distance of about *one quarter of a mile*. In addition, control of flowering with a highly commercial crop, *Chrysanthemums*, can also be obtained with a laser. The results in Figure 8 are of *Chrysanthemums* that were given six long nights to induce them to flower. The left curve is the course of floral development with time. If plants got less than 6 inductive nights they had a slower rate of floral development. On the right-hand side the effects of interrupting those 6 inductive nights with the laser are indicated. Obviously 1000 secs. night interruption completely prevented flowering. It can be concluded that a Helium-Neon laser is effective in controlling at least some photoperiodic responses, can operate at distances of at least 1/4 mile, and can work on commercially important crops.

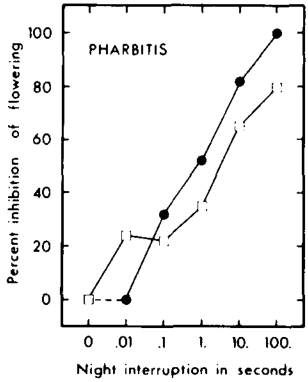

Figure 6. Results of duplicate experiments with different length night interruptions with a 50mW Helium-Neon laser on floral development of *Pharbitis* (intensity at leaf surface about 8 mW/cm^2).

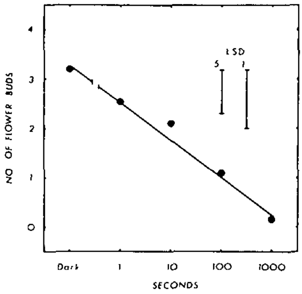

Figure 7. Inhibition of flowering of *Pharbitis* induced by different length night interruptions with an 8 mW Helium-Neon laser at a distance of 1,230 feet (intensity at leaf surface about 0.15 mW/cm^2).

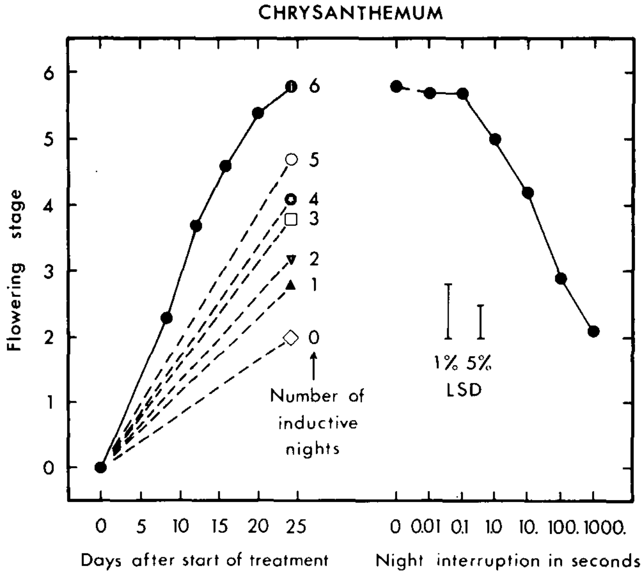

Figure 8. Rate of development of floral apex of *Chrysanthemum* with different numbers of inductive nights, and effect of different length night interruptions with a 50 mW Helium-Neon laser on flowering stage after 24 days of plants receiving six inductive nights.

However, there are important problems to be solved before lasers can be used in commercial operations. For example, the absolute limiting factor in any contemplated use of night interruption is the requirement of the plant. Let's consider a plant, for example, whose flowering, or fruit coloration or leaf or stem growth can be controlled by a night irradiation sometime during a 4 hr. period. In 4 hrs. there are 240 mins. or 14,400 biologically effective secs. during the potentially effective interruption period. If it were possible to disperse the laser light as a constantly scanning spot, moving at a controlled speed, the maximum area that could be irradiated each night would be determined by the least effective amount of irradiation applied for the shortest effective period. The last factor contributing to the calculations is the spot size. As the intensity of lasers increases, the biologically effective dose can be kept constant by increasing the size of the spot. It should be pointed out that the control and integration of these factors is a relatively simple engineering problem. The major missing factor is the relevant biological information.

Finally, how would one use a laser for these effects? Well, one might envisage circular glasshouses or glasshouses arranged like the spokes of a wheel to facilitate maximum use of a single laser. One can also picture a laser beam reflected up a pole or tower to a mechanically- or electronically-controlled mirror which could be preset to scan different size fields at different rates of speed for differing lengths of time.

At the moment, the capital cost of high intensity lasers is high, but the energy inputs are quite small for the amount of biologically active light produced. It seems likely, however, that when a commercial use requiring reasonable production numbers is found, the cost per laser will be drastically reduced.

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