to introduce Dr. Roy Sachs, now of the Dept. of Landscape Horticulture, University of California, at Davis.

THE USES AND LIMITATIONS OF SUPPLEMENTARY LIGHT IN CALIFORNIA NURSERIES

Roy M. Sachs and Chas. F. Bretz

University of California
Davis and Los Angeles, California

Piringer (6) has reviewed the main discoveries showing that growth and development in woody plants are greatly dependent upon day length. We have been particularly interested in commercial application of these findings.

Some parts of coastal Southern California are noted for relatively mild spring and autumn temperatures, perhaps suitable for optimum plant growth and generally considered to have a growing season of 250-300 days (9). Optimum day lengths[1], however, prevail for no more than 90-120 days of that period; indeed, most species make the major portion of growth during late May to early September. Thus, it might be expected that supplemental lighting that creates summertime (greater than 14 hours) day lengths throughout the "growing season" might have great value in promoting the growth of nursery plants--perhaps to the extent of doubling the growth per year of many species.

In our initial experiments at and around the University of California at Los Angeles, these exciting possibilities were seldom realized. The reason is probably an over-optimistic estimate of the spring and fall temperatures. In other words, the "growing season", as presently defined, is by no means a broadly applicable term, and does not mean that the prevailing fall through spring temperatures will support growth of all plants, particularly the growth of leaves and stems.

As our greenhouse work progressed, however, some useful information has been collected. This paper presents the results and conclusions.

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1 Optimum day length must be defined for each species; however, in this paper we assume that for most plants day lengths in excess of 14 hours fall into the "optimum" category. Some support for this figure appears in the literature (5). In the Los Angeles area (at the 34th parallel), greater than 14 hour day lengths occur from April 21 to August 21. This includes the sunrise to sunset hours plus 1/2 hour twilight at dawn and again at dusk.

MATERIALS AND METHODS

The plants used were mostly obtained from nurseries as "liner stock"[2], a few were propagated from cuttings available on the UCLA campus, and a few were from seeds collected locally. In all cases the plants were introduced into experimental conditions when they were in the liner-stock category, no more than 6-10 inches (15-25 cm.) above the containers. The potting mixture was a standard peat-enriched sandy loam supplemented with fertilizers, and throughout the experiment all plants received periodic applications of liquid fertilizer (according to standard procedures described elsewhere).

To create long day (LD) conditions in the greenhouses and outdoors, the plants were lighted between 10:00 p.m. and 2:00 a.m. by incandescent lamps yielding 10 foot candles, 18 inches above the bench or ground surface (4,7). In some cases (cited in Table I) 16 hours of supplementary light was used to establish LD conditions. Short day (SD) conditions in the greenhouses were obtained by covering benches with black cloth at 4:00 p.m. and uncovering at 8:00 a.m. daily. Circulating air under the black cloth kept temperatures there almost equivalent to those on the uncovered benches. Minimum temperatures in the greenhouses were 15 to 18° C. (60 to 65° F.); outdoors, temperatures were the same in natural day length (ND) areas.

Plant height was recorded as the distance between the container and terminal cluster of leaves. Measurements were made monthly.

RESULTS AND DISCUSSION

Although our main interest was in vegetative growth, reproductive development (in the greenhouses) was also observed. The results are presented in separate sections according to the type of observation and conditions.

Vegetative growth. Of the more than 40 species tested, only a few warrant special attention. Table I gives a complete list of the plants tested and an evaluation of the effects of supplemental lighting. The "outdoor"[3] results, of course, pertain only to climates resembling that at UCLA.

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2 We thank the Four Winds Growers for donating several varieties of dwarf citrus, and the Select Nurseries, Inc. for the Bougainvillea plants. Mr. Richard Maire and Mr. Wesley Humphrey of the Agricultural Extension Service have been extremely cooperative in locating materials and suggesting application of this research.

3 Marston Kimball, of the Agriculture Extension Service, is preparing a plant-climate zoned map of California that should be particularly useful for extending information such as contained in Table I to other areas of the state.

OUTDOOR LIGHTING

Pinus radiata (Monterey pine) was far and away the most responsive plant. With regard to height alone, supplemental lighting increased the growth rate more than twofold during the February-April period (Fig. I). Increased growth was also reflected in greater stem diameter and lateral bud development. In all respects the lighted plants were more valuable than the untreated specimens, and ready for transplanting to 5-gallon containers several months sooner. As the treatment continued, however, the growth rate of the lighted plants fell below that of the controls. The reasons are not clear, though growth cycles during continuous LD treatment are well known for other species of the pine family (5).

Subsequent short-term experiments with P. radiata and other plants revealed still another feature of outdoor (OD) supplemental lighting: that spring lighting did not speed growth every year. Variable temperatures were presumably responsible, and the data in Table II support the view that low spring temperatures completely nullify the response to supplemental light. OD treatments were much less effective than those in the greenhouse, and the principal difference between the two was the lower temperatures prevailing outdoors. (Juniperus keteleeri was the only species that grew as well outdoors as in the greenhouse). In this respect it is of great interest that supplemental lighting has been more successful in the fall than in the spring. (Fig. II). This can be attributed to the warmer weather in September, October, and part of November than in March, April, and May.

Under lights, Erythrina and Albizzia retained their leaves several months longer than unlighted plants, and showed the greatest promise for increased growth through supplementary lighting in the fall (Fig. II). Moreover, stem "die-back" was considerably less on the lighted Erythrina plants. "Die-back" is surely one of the most undesirable features of E. cristogalli, and supplemental lighting may be of value for this use alone.

Several investigations have shown that below a certain minimum temperature--21° C. (70° F.) is commonly quoted--the response of woody plants to supplemental light is greatly reduced, and in some cases may disappear entirely (3,5). The question of temperature is so important that, before OD supplemental lighting can be recommended as a standard nursery practice, steps must be taken to maintain temperatures higher than that of the surrounding environment (in certain areas and times of the year in California, as much as 15 to 20° F. higher). Do the increased costs for lights and cover (for example, that provided by a polyethylene greenhouse) justify the benefits? The economic bases upon which nurseries operate are not widely published, and it is not possible to estimate the value of increased growth rates (which are eventually reflected as increased productivity or faster turnover on reduced acreages). It is really from the economists rather than the physiologists that we require the greatest amount of data.

GREENHOUSE LIGHTING

Except for Cycas revoluta, Macadamia ternifolia (which grew poorly under all conditions), Acer paxi, Bougainvillea brasiliensis, and Viburnum japonicum, every species tested responded to LD treatments in the greenhouses. In some cases the differences between long and short days were truly spectacular: Jacaranda, Magnolia, Acer palmatum, Quercus borealis, Thuja bakeri, Libocedrus decorrens, Juniperus keteleeri, and Pinus halepensis more than doubled their growth rate with LD, at least for the first four months of treatment. Some trees showed the typical SD dormancy response: Betula alba, Acer palmatum, and Quercus borealis were in this category, although after several weeks the buds opened even under SD conditions. Chilling requirements to break dormancy were not tested although, in every case, the plants had already been exposed to low temperatures in December and January in the Azusa-Monrovia, California area.

Reproductive Development. Supplementary lighting was also directed toward the problem of hastening flowering in woody plants. For example, if the generation time could be decreased by day length controls, breeding programs could be accelerated in this otherwise difficult group of plants.

OUTDOOR

Regardless of the day length, several plants were observed to flower during the first year of cultivation: Jacaranda, Bauhinia, and Magnolia were the most surprising cases, since they are generally vegetative for several years under ordinary nursery and landscape conditions. The forced feeding and soil conditions presumably reduced the time to reach maturation, and these studies should be extended to check for fertility and fruit set wherever breeding programs are in progress.

With supplementary lighting, camellias and azaleas were delayed about one month in bud development, and there were many "by-pass" shoots. That is, the flowers were confined to the lower axillary buds, with the terminal buds generally vegetative. This characteristic is highly undesirable commercially where masses of terminal flowers are required for showiness. However, the lighted plants showed faster growth, and during the first year of propagation, when flowering behavior is not very important, some value may be derived by supplemental lighting.[4]

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4 Dr. Harry Kohl, of UCLA, has shown similar effects of day length upon azaleas in much more detailed experiments, studying both temperature and day length simultaneously. He has found that all varieties do not respond equally and some do not respond at all to supplemental lighting.

GREENHOUSE LIGHTING

A by-product of our screening program was the discovery that many varieties of Fuchsia hybrida are very good LD plants with respect to flower initiation (8). Full-blooming fuchsias have been produced in mid-winter by the use of supplemental lighting in the greenhouse and, for display purposes, nurserymen should find day length-controlled flowering of some value. Bougainvillea, as reported by Allard (1), is an SD plant, and in our greenhouses three varieties behaved in this manner. Under black cloth, flowering plants were obtained in mid-summer whereas lighted plants remained completely vegetative. Since these plants bloom profusely outdoors in late spring and early summer, it is clear that other important contributing factors affect flower initiation and development in Bougainvillea.

CONCLUSIONS

Long days promote vegetative growth in a wide variety of plants commonly grown in California, but the temperature requirement of the plants is too high to obtain consistently increased growth rates in outdoor nursery plots by the simple expedient of supplementary lighting. If economical methods can be developed to maintain 60 to 70° F. minimum night temperatures throughout the year, however, supplementary lighting might well become standard practice in nurseries. In some areas autumn temperatures are high enough for lighting on an experimental basis, and OD lighting should be given extensive field trials in more genuinely tropical climates (such as Southern Florida, Gulf of Mexico, areas, and Hawaii). We believe that with supplemental lighting, average temperatures between 65-70° F. will support nearly optimum stem growth and leaf initiation.

Our experience outdoors has shown that this kind of average is most easily met if the night temperatures do not fall below 60° F. for any prolonged period. It is no coincidence that maximum response to supplemental lighting occurs in September and October when the above mentioned temperature conditions prevail at UCLA (10).

A major application of day length control in nurseries, regardless of area, may be to induce permanent (overwintering) or temporary (7-14 days) dormancy during the summer by creating SD conditions. Temporary dormancy, or hardening, in plants may be of great value for summer landscaping jobs, where water stress is probably the greatest factor contributing to the loss of plants. Although this idea has not been field tested, it is clear from our greenhouse experiments (Table II) that many plants grow slowly if at all under SD conditions.

FUTURE RESEARCH

One long-term goal of our research is in the area of defining the minimum and optimum temperatures required for response of plants to supplementary light. Environment-controlled facilities such as that available at UCLA are well-suited to this type of problem.

Another critical problem is that of growth cycles in woody plants, which seems to be the case in Pinus radiata. It may not be possible to force prolonged rapid growth in many species, owing to little understood internal growth requirements.

From the standpoint of commercial application of supplementary lighting, research is required on means of heating (by plastic covers to use re-radiation of solar energy or other methods) large areas of plants, and on the most efficient use of artificial lights for extending the natural day length. Several recent studies suggest that intermittent (or cyclic) lighting is considerably more efficient than a 4-hour interruption of the night, as done in most of our experiments (2).

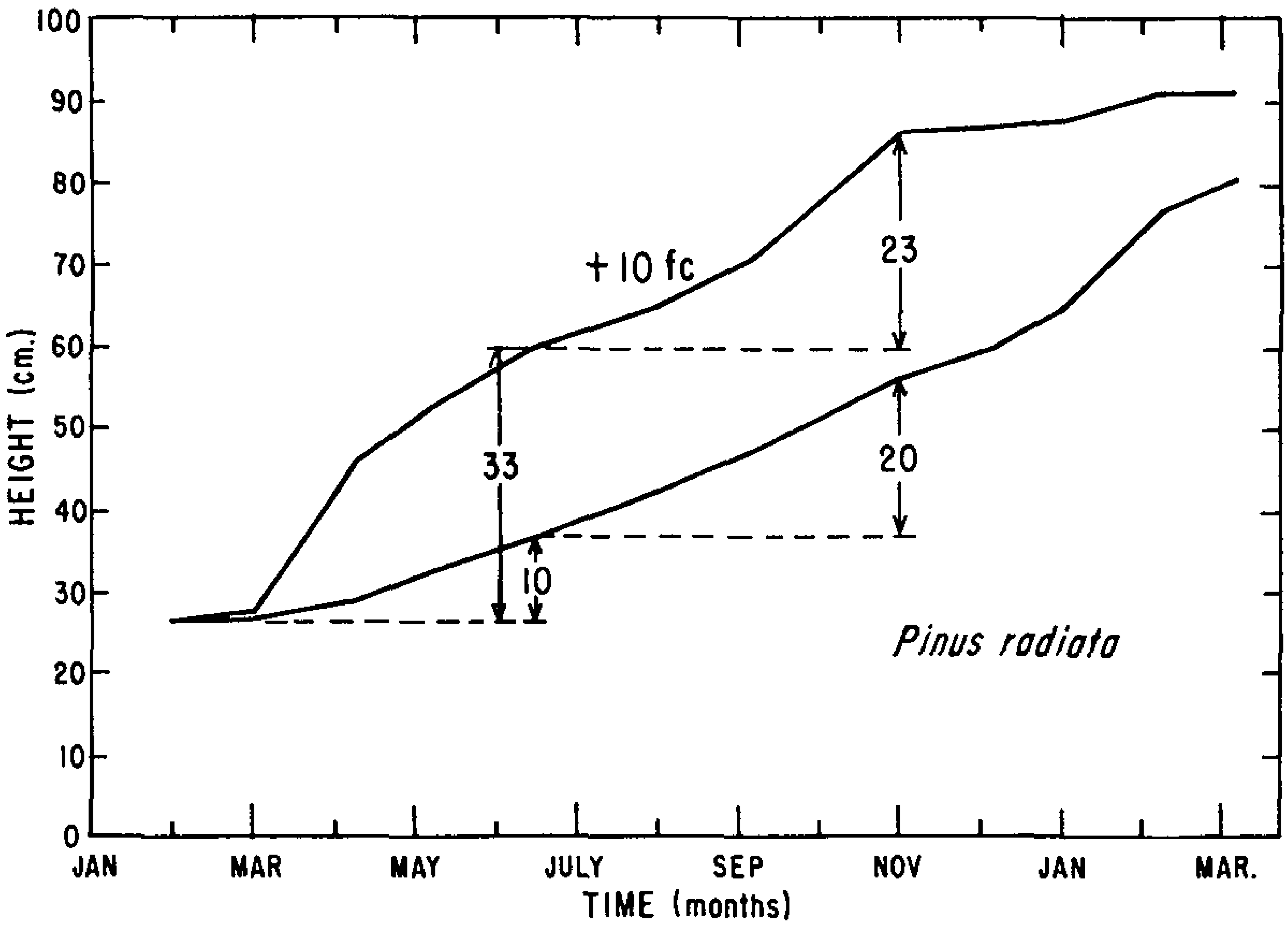

Fig. I.

Stem growth of Pinus radiata outdoors. Upper curve - 10 ft. c. light daily for four hours; 10:00 p.m. - 2:00 a.m. Lower curve - natural day length.

Note 1). that the maximum response to supplemental light occured in the first 3-4 months, and 2). that the growth rate of the lighted plants was less than that of the natural day length controls in the November through March period.

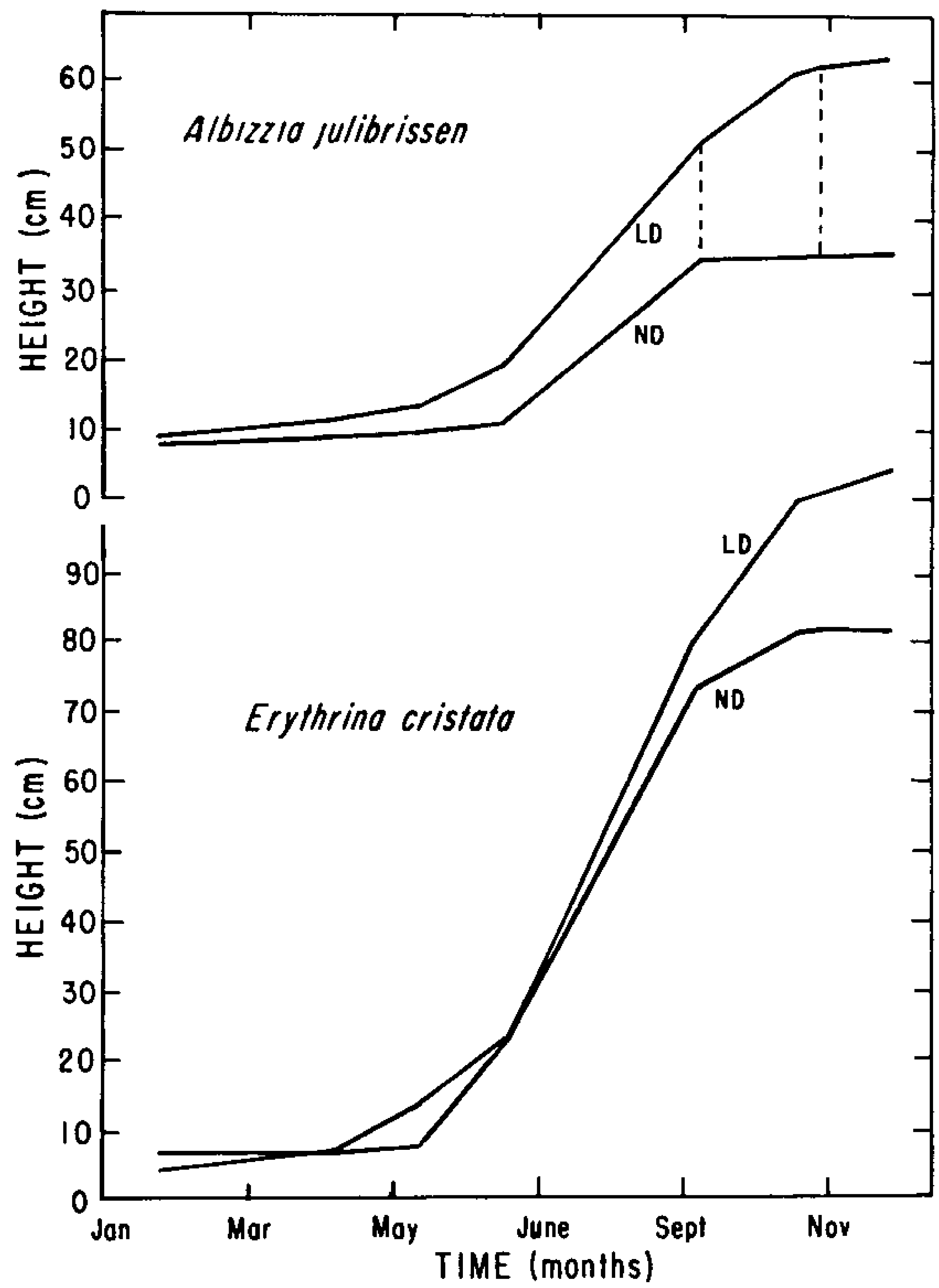

Fig. II.

Stem growth of Albizzia julibrissen and Erythrina cristata outdoors. Upper curves - 10 ft. c. light daily for four hours, 10:00 p.m. - 2:00 a.m. Lower curves - natural daylength. Note that response to supplemental light was greatest in the September - October period.

TABLE I

Evaluation of Supplementary Lighting on Vegetative Growth. UCLA, 1959, 60, 61.

Plants tested	Outdoors[1]	Greenhouse[1]
Gymnospermae		
(Cycas revoluta)..................	0	0
Pinus radiata......................	+,(+)	+,-
P. halepensis......................	0	+,-
P. canariensis.....................	0	+,-
Juniperus chinensis "Keteleeri"....	+	+,-
" " "pfitzeriana"..	0	
Thuja orientalis "Bakeri"..........	0	+,-
Cupressus sempervirens glauca......	0	+,-
Libocedrus decurrens...............	0	+,-
Cedrus deodara.....................	0	
Angiospermae - deciduous		
Acer palmatum atropurepureum.......	0*	+,*,-
Albizzia julibrissen...............	+,(+)	
Betula alba........................	0	+,-
Erythrina crista-galli.............	+,(+)	
Liquidambar styraciflua............	0	
Quercus borealis...................	0	+,-
- evergreen		
Acer paxi..........................	0,*	0,*
Azalea.............................	+	
Bauhinia...........................	0	
Bougainvillea "Barbara Karst"......		+
" "San Diego Red"......		+,*
" "Brasiliensis".......		0
Buxus harlandi.....................	0	
Camellia...........................	+	
Camphora officinalis...............	0	
Ceratonia siliqua..................	+,(+)	
Citrus (dwarf): Robertson navel orange, Eureka lemon, Owari Stasuma mandarin, Kinnow mandarin, Nagami Kumquat.	0	

Plants tested		
Anigiospermae - evergreen		
Daphne odora.......................	0	0
Ilex crenata convexa...............	0	
Leptospermum flore pleno...........	0,*	+,*
Jacaranda mimosaefolia.............	0	+,-

TABLE I,(Continued)

Plants tested	Outdoors	Greenhouse
Anigiospermae - evergreen (continued)		
Macadamia ternifolia...............	0	0
Magnolia grandiflora..............	+,(+)	
Pyracantha gregeri.................	0	+
Schinus molle......................	0	
Viburnum japonicum.................	0	0
Xylosma senticosa..................	0	

Evaluation Code:

+, promotion with supplementary light
0, no response to supplementary light
(+),promotion in spring months not observed regularly
-, reduction of growth in short day below that of plants in natural day lengths
*, continuous low intensity light promotes growth above the standard, 4 hour interrupted night treatment

1. 5 plants per treatment.

Supplementary light and short day conditions are described in the text.

TABLE II*

Supplementary lighting effects in Greenhouse and Outdoors[1]

		Pinus halepensis L(cm) 75 days	Pinus halepensis L(cm) 135 days	Juniperus chinensis Keteleeri L(cm) 75 days	Juniperus chinensis Keteleeri L(cm) 135 days
GH	SD	4	7	3	4
	LD	13	27	11	24
OD	ND	6	13	7	20
	LD	8	15	8	32

		Thuja orientalis Bakeri 75 days	Thuja orientalis Bakeri 135 days	Acer palmatum 75 days	Acer palmatum 135 days
GH	SD	2	3	1	2
	LD	10	22	34	105
OD	ND	5	8	6	25
	LD	6	11	9	36

* L - growth in height after 75 and 135 days of treatment

GH - greenhouse

OD - outdoors

SD - short day

LD - long day

ND - natural day

[1] 5 plants per treatment

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