THIRD SESSION

LIGHT AND THE PLANT PROPAGATOR

A.E. CANHAM
Applied Research Section
Department of Horticulture, University of Reading

The task of the propagator is to produce a good quality plant in the shortest possible time, either from seed or from cuttings, and to do this as economically as possible. In this he is very much dependent on the facilities at his disposal for manipulating the environment of his material.

Over the years techniques have been developed to enable him to optimise a number of environmental factors either by a process of trial and error or as a result of research — for example the control of bed temperature, the use of mist propagation techniques, etc. However, one very important factor has received relatively little attention, and that is the light on which the seedling or cutting is so dependent. For a large part of the year light may be regarded as the most important factor, in that it is the one which is limiting growth or development in one way or another.

Growers are now beginning to realise the magnitude of this limitation and an increasing number have sought to effect some form of improvement in the performance of their plants by the use of artificial light. Whilst this has been especially true of those raising plants from seed, nevertheless a number of growers concerned with rooting cuttings have also started to investigate the possibilities of this additional tool. They are hampered to a considerable degree by the lack of experimental data on which to base their efforts and they are therefore forced to adopt an empirical approach. This is likely to be most rewarding when the fundamental principles involved are more fully understood and the characteristics and capabilities of the equipment available are better appreciated. The object of this paper is to consider the latter in relation to these principles, and to summarise the present position, in order to see how artificial light may best serve the propagator both now and in the future. A more detailed discussion of these principles and their practical application has been published elsewhere (2).

RESPONSES TO LIGHT. It is important to distinguish between a number of plant responses to light for these to be efficiently controlled. In the first place, light is the energy source for photosynthesis and when light is in short supply this process slows down. Logically, therefore, in such a situation, an improvement can be effected by supplying additional light from an artificial light source. There are, however, other interdependent factors — such as air temperature, CO_2 level, water supply, etc. — which must be non-limiting if the full advantage is to be obtained from this extra light

In photosynthesis light energy is absorbed, largely by the leaves, and the rate at which the photochemical process proceeds is determined mainly by the irradiance of the incident light, other factors being non-limiting. The amount of growth made by a plant in a given period of time is therefore dependent both on irradiance and on the length of time it has been exposed to this irradiance, i.e. on the total light energy received during this period. Under natural light conditions the irradiance varies from moment to moment and so therefore does the rate of photosynthesis and growth; this has led to the concept of the "light integral", the product of irradiance and time, and given by the area under the irradiance/time curve.

The rate of growth can therefore be increased either by increasing the irradiance, extending the daily period of exposure to light or by both. In order to improve the rate of growth appreciably the amount of artificial light given daily must be at least of a similar order of magnitude to that received naturally, and this is relatively high by illuminating engineering standards, even during the light-deficient months of winter.

Daylength. There is a second major plant response, or rather a series of responses, to light in which light performs more of a managerial function in controlling the way in which the products of photosynthesis are used These responses are sensitive to the length of the daily dark period and are known as photoperiodic or daylength responses A further characteristic is that they are activated by comparatively low levels of irradiance.

The most widely known response of this type is that of the flowering process leading to the categorisation of plants into "long-day plants", which will only flower when the daylength is greater than a critical value, "short-day plants" which will flower only when the daylength is shorter than a critical value, and "day-neutral" plants which show no sensitivity to daylength. This simple grouping proved to be quite inadequate, as it was found that in some cases the requirements for flower initiation differed from those for flower development — leading to short/long-day plants and vice versa — and also in other cases the daylength requirement proved to be temperature sensitive.

It was later found that many other processes were day-length sensitive, including two of particular importance to the propagator, namely, the onset of leaf fall and dormancy in perennial plants and also the initiation and growth of roots on cuttings. In spite of their significance in the nursery stock industry, surprisingly little research has been undertaken on these responses.

There are a number of stages in the growth of plants in which light responses are of importance to the propagator. These are (a) when the cutting is still attached to the stock plant, (b) when it is in the rooting bench, and (c) after it has been potted on.

Experience has shown that there are times of the year when cuttings will root most readily and this is largely due to the physiological condition of the cutting as determined by the prevailing environmental factors. Unfortunately, far too little is known about the role these factors play in the production of the growth substances which control root initiation and development in the cutting. Evidence has, however, been published which suggests that some species of *Salix* and *Cornus* show a rooting response in the cutting that is dependent upon the day length in which the stock plant has been growing (6, 13). This information is not sufficient to be of great help to the propagator at the present time, but it does emphasise the need for research on this aspect of propagation.

More work has been reported from the U.S on the direct effects of daylength on the rooting of cuttings (13). *Abelia grandiflora, Cornus florida* and *Magnolia soulangeana* cuttings appeared to root best in an 18 h day, but continuous light was best for *Salix blanda* and *Weigela florida* Again there appears to be sufficient evidence that daylength does play a role but not enough to enable the propagator to make practical use of this technique.

Some growers have, however, considered it sufficiently worthwhile to undertake trials themselves. A grower in the Midlands, for example, reported a 65-70% "take" with *X Cupressocyparis leylandii* by the end of December whilst the corresponding plants in natural short days had shown no signs of rooting (9). Success was also reported with *Chamaecyparis lawsoniana, Thuja occidentalis* 'Rheingold', *T. orientalis* 'Decussata' and *Juniperus horizontalis* 'Glauca'

In other trials, high-intensity light has been used to lengthen the day, with the result that it is not possible to separate any possible responses to daylength from effects due to higher rates of photosynthesis In such trials at Kinsealy, supplementary high-intensity light during the day failed to produce the improvement in rooting found with *Chamaecyparis lawsoniana* 'Fraseri' and *C. pisifera* 'Aurea' which resulted from a similar treatment given during the night (5). This suggests that it was a response to daylength rather than high light intensity and if this is so, it could be obtained with a much cheaper and simpler lighting installation.

True long-day lighting techniques have been used by some growers to delay the onset of dormancy and extend the rooting period of deciduous azaleas, but it is in the later stages of rooting and after potting on that this has been found of particular advantage.

If the rooted cutting is allowed to go dormant before it has established an adequate rooting system, overwintering problems can be serious, and the use of long-day lighting to delay dormancy has proved beneficial in deciduous azaleas, *Betula papyrifera* and some

Acer spp Work in the U.S. has demonstrated the continuation of extension growth in many ornamental trees and shrubs (7,12) but at temperatures far higher than the British grower would contemplate Work by David Whalley and K. M. Cockshull at the GCRI (14) and Margaret Scott at Efford EHS (10) has shown a similar — if less spectacular — response in some species of *Acer, Cornus, Weigela, Berberis* and some conifers.

Trials at Boskoop have suggested that this technique may even have possibilities in the summer, when all-night lighting has resulted in continued extension growth with a number of species of woody shrubs and trees (4).

More detailed discussions on the photoperiodic responses of woody plants have been published by Nitsch (8) and Wareing (11).

EQUIPMENT FOR ARTIFICIAL LIGHTING When the use of artificial light is proposed in order to provide further control over the environment, it is important first of all to decide whether it is required to provide a long-day treatment or to boost a slow growth rate due to reduced photosynthesis in poor winter light. This may be especially important as slow winter growth may be due to short-day dormancy rather than low natural light integrals. Long-day treatment is relatively cheap and easy to provide, but supplementary lighting for increasing photosynthesis is much more expensive.

Long-day treatment. A long-day response may be promoted either by extending the length of the natural day by switching lamps on at dusk, or by providing a few hours of "night-break" light in the middle of the night. In either case, relatively low irradiance levels from incandescent lamps (sometimes called tungsten-filament, or general lighting service lamps) are effective. Threshold levels have not been determined but a minimum of 50 lux is normally aimed at in the case of the flowering control of year-round chrysanthemums and a level of 60 lx has been used successfully in trials at the GCRI Until more is known about the responses of ornamental nursery stock it is suggested that a rather higher figure, say, a minimum of 200 lux, should be used, which can subsequently be reduced if a positive response is obtained. The arrangement of lamps needed to provide this will depend on the width of bench or standing ground to be covered, but 150 W lamps, six feet apart and 4 ft to 4 ft 6 in above the plants, should be effective over a width of about 5 feet, using a simple aluminium foil reflector.

Cables are available with moulded lampholders at appropriate intervals; these are quite suitable for this purpose and are widely used in year-round chrysanthemum and carnation production. They may be switched on at dusk to extend the daylength to 16 h, 18 h or even 24 h as required, or for about 4 h to 5 h in the middle of the night to provide a "night break". There is not yet sufficient information available to enable any particular regime to be recommended for the propagator, but satisfactory results have been obtained at GCRI and Hadlow with dusk-to-dawn lighting and at Efford EHS using an extended night break from 23.00 h to 07.00 h. The effects of various daylengths — including a night break — were compared by Nitsch (7) on a range of woody shrubs and trees.

Supplementary Light. High-intensity supplementary light is now being used increasingly by growers of tomato, lettuce and bedding plants and a range of suitable lamps is now available. Irradiance levels in the range 5,000 to 15,000 lux are currently being used, depending on the subject, but any propagator considering a trial installation of this type would be well-advised to aim for the lower level in the first instance. It is a much more expensive technique than long-day lighting and for maximum economy should be restricted to areas containing large numbers of closely spaced plants. This points to the rooting bench as the most obvious location but there is still relatively little known about the role of photosynthesis in the rooting process.

It may well be that the requirements vary between the early stages when a callus is being formed and roots are being initiated and the later stages of root growth.

Light sources. The lamp which has been most widely used in supplementary-lighting installations in recent years has been the high-pressure mercury-flourescent lamp with its own built-in reflector. This is known as the type MBFR/U lamp and is available in a range of sizes from 125 W to 1,000 W. The 400 W size has been the most popular for bench work but in a number of installations, where large areas are appropriate and paths are narrow, the 1 kW lamps have been used. A variation on the standard type is also available in the 400 W size only and is known as the HLRG lamp; it is said to be free of ultra-violet radiation which can prove detrimental to some sensitive species. In these lamps the light is produced in a quartz arc tube containing mercury vapour and the outer bulb carries a fluorescent powder which adds red light to the basic blue/green of the original arc, giving a whitish coloured light.

The same principle is used in the fluorescent tubular lamp, or "fluorescent tube" as it is often called, but these are low-pressure lamps of limited output so that a large number are required to provide high illuminance levels. Furthermore the arc is contained within the outer tube rather than a separate arc tube. Sizes range from lamps 6 in. long x ⅝ in. diameter and rated at 4 W up to 125 W lamps 8 ft. long. Some have built-in reflectors.

They are available in a wide range of light colours from blue through to red and including several different shades of "white". The colours known as "warm white" or "white" are those most frequently used for plants. Special "plant growth" lamps have been produced from time to time, usually containing a mixture of blue and red light with very little green, but so far there appears to be little scientific evidence to indicate that they offer an overall economic advantage.

The 125 W 8 ft lamp is currently the one most widely used horticulturally. It can be suspended with its long axis parallel to the sides of the bench with an unequal spacing to give maximum uniformity of illuminance, but it is more economical when mounted across the width of an 8 ft. bench. A reflector board is necessary above the lamps to ensure that the maximum amount of light is reflected down on to the plants, but due to its large size, it effectively cuts out most of the natural daylight which one is trying to supplement! Such a reflector is less essential with lamps with their own built-in reflector, and these should be seriously considered if the fluorescent tubular lamp is to be used. For this reason, together with considerations of size, this type of lamp has considerable disadvantages compared with the higher-powered lamps. On the propagating bench a further disadvantage is its low mounting height (ca. 18 in above the bench) which is too low for mist propagation nozzles. Its adavatages, however, lie in the small amount of radiant heat the lamps produce, which minimises the rise in leaf temperature, and in the better uniformity of light distribution.

Recent Developments. More recently, interest has centred round three further lamp types: two relatively new lamps and the third a street lighting lamp, the efficiency of which has improved dramatically over the years so that it has become the most efficient currently available.

The first of the new introductions is the mercury halide lamp, which is basically a high-pressure mercury lamp with rare earth halides added to the mercury in the arc tube. This results in further radiation in the yellow and red region of the spectrum to give a whitish light without having recourse to a fluorescing powder on the outer bulb. Such lamps are compact and the 400 W size can be operated in a plant irradiator fitting, originally developed for the earlier mercury-vapour lamp. Its cost is, however, higher than that of the MBFR/U lamp.

Another recent introduction is the high-pressure sodium lamp which emits a golden yellow light. This is also available in various sizes and in two shapes of which the 400 W type SON/T is of most interest to the grower. Its high efficiency means that it can be mounted further from the bench and covering a wider area than the corresponding MBFR/U lamp. This is, however, only of value on wider benches. It, too, can be used in the mercury plant irradiator fitting, but again the cost is relatively high.

Finally, the low-pressure sodium street lighting lamp, type SOX, is now creating a considerable amount of interest due to its high efficiency. Of the sizes available, the 180 W appears to offer the greatest advantage. In spite of its limited spectral output — virtually all the radiation is in a double spectral line at 589 nm — many plants appear to grow satisfactorily when this is used to supplement daylight. This is, no doubt, due to the spectral qualities of daylight making up for any deficiencies in the monochromatic sodium light. Horticulturally, it is still in the experimental stage but it does appear to offer definite economic advantages over other lamps. A reflector has been designed for it and this is now commercially available.

Control gear. Unfortunately, all the lamp types mentioned, with the exception of the incandescent lamp, require certain items of control gear for their efficient operation. These usually comprise a choke, a power-factor correcting capacitor, and sometimes some additional starting equipment. This can form an appreciable part of the cost of an installation but is unavoidable. Some provision must be made for this control gear to be mounted in a convenient position not too far from the lamps and protected from moisture.

The choice of lamp. With so many alternative light sources at one's disposal, the final choice must be made based on a number of relevant factors. Foremost amongst these must inevitably be the question of economics which, in turn, depends largely on the shape and extent of the area to be covered and the arrangement of lamps which gives the most efficient installation.

Physical limitations on the mounting height — headroom, clearance of mist nozzles, etc. — also have a bearing on this. It is, therefore, not possible to generalise and growers are recommended to take advice for their own particular circumstances. Some data are included in the appendix to provide a guide to the comparative costs. They are taken from a report by Cooke (3) and reproduced by permission of the Electricity Council. They apply only to benches 3 ft to 3 ft 6 in wide; further calculations are required for wider benches.

Lighting period. In Britain light is limiting for 3 to 4 months during the winter. Data from the Lee Valley EHS have shown that the long-term average daily light integral (of photosynthetically-active radiation on the bench inside a glasshouse with an average transmission of 60%) falls below 0 75 $MJ.m^{-2}$ for three months, with daily values falling to about 0.31 $MJ.m^{-2}$ For a large area of the country to the north of this station the position is even worse.

Current recommendations for lighting chrysanthemums call for a daily minimum of 1 25 $MJ.m^{-2}$, of which 0.94 $MJ.m^{-2}$ are required to be provided artificially. As the daylength is limited to 12 h during the short-day period of these plants, this requires an installation capable of providing a level of 7,200 lx of light from MBFR/U lamps for 12 h/ day. This would be a reasonable starting point for empirical trials on nursery stock but the 12 h per day restriction would no longer apply. Extending it to 16 h per day would require only 5,400 lx to provide the same daily light integral. The corresponding figures to give the same daily total of photosynthetically-active radiation with the other lamps mentioned would be: fluorescent tubes, 6,000 lx; mercury halide, 5,400 lx, SON/T, 7,000 lx and SOX, 7,800 lx.

It might even be possible to provide the artificial light continuously for 24 h per day with further economies in installation cost.

Growing rooms. A further technique of using artificial light in commercial horticulture is the use of growing rooms. These are rooms from which daylight is excluded and the plants grown entirely in artificial light. This gives good control over climatic factors in the winter and eliminates the variable features of the natural light climate. Such rooms are currently being used for raising bedding plant seedlings and young tomato and lettuce plants, but at least one is being used commercially for the rooting of pelargonium cuttings.

The lamps used in such rooms are almost exclusively warm-white or white fluorescent tubes, arranged to give a total of 8,000 lx or 15,000 lx. Full details of such rooms are given in an Electricity Council booklet (1)

CONCLUSIONS

Artificial light provides an additional means of effecting some control over the growth of a wide range of plant species of interest to the propagator. At present, however, very little information is available to guide him in the use of this new tool and there is scope for much research to establish the responses of a large number of important species to provide him with this information. A number of lamp types are available which can be used to provide long-day conditions, or to speed up the processes of photosynthesis and growth, but the choice depends ultimately on the conditions prevailing on any particular nursery.

Until the required information is available, growers will naturally be tempted to conduct their own investigations. This can prove difficult and inconclusive unless they are properly carried out, and any grower interested in doing so would be well advised to consult the Ministry's nursery stock specialists before embarking on such a course.

LITERATURE CITED

1. Anon. 1972. Growing rooms. *GrowElectric Handbook No. 1*, pp. 72, Electricity Council, London.
2 Canham, A. E. 1966. *Artificial light in horticulture.* Centrex Publishing Co. Eindhoven. pp. 209

3. Cooke, I. J. 1970. Supplementary Lighting — which lamp? *Electtricity Council Research Center, Memorandum/ ECRC/ M* 260, p13.
4 Doesburg, J. van. 1962 Belichting van jonge planten in do bak. *Proefst, Boomkw, Boskoop, Jaarboek.* p 138-141.
5. Lamb, J. G. D. and J. C. Kelly, 1971. The propagation of *Chamaecyparis lawsoniana* cultivars. *Gardeners Chronicle-HTJ, 169 (5),* 19-22.
6. Moshkov, B. S. and I. E. Kocherzenko. 1939. Rooting of woody plants as dependent upon photoperiodic conditions. *Dokl. Akad. Nauk. SSSR 24 (4),* 392
7. Nitsch, J P. 1957 (a). Growth responses of woody plants to photoperiodic stimuli. *Proc. Amer. Soc. Hort. Sci. 70,* 512-525.
8. Nitsch, J.P. 1957 (b). Photoperiodism in woody plants *Ibid, 70,* 526-544.
9. Sanders, C. R. 1970. Conifer propagation with light. *Gardeners Chronicle — HTJ, 168 (18), Lighting Supplement,* 5.
10 Scott, M. A. 1972. Personal communication
11. Wareing, P. F. 1956. Photoperiodism in woody plants *Ann. Rev. Plant Physiol. 7,* 191-214.
12. Waxman, S. 1957. The development of woody plants as affected by photoperiodic treatments. Ph.D. Thesis, Cornell Univ., Ithaca, N.Y. pp 193.
13. Waxman, S. 1958. Light treatment in the propagation of woody plants. *J. New York. Bot. Gdn. 8,* 139.
14. Whalley, D N. and K. E. Cockshull. 1972. Some effects of photoperiod on the rooting of cuttings. *Nurseryman and Garden Centre 155 (6),* 138-9.

APPENDIX

In Table 1, which is based on one prepared by Cooke (3) and included by permission of the Electricity Council, the characteristics and costs of a range of lamp types which may be suitable for supplementary lighting purposes are compared. The initial capital costs include the cost of the control gear (ballast, capacitor and ignitor where necessary) the lampholder or reflector and the lamp, allowing 13% discount off the manufacturer's recommended prices but not including the cost of installation. Gear cost is spread over 10 years but no allowance is made for interest charges and the cost of a SOX relflector is taken to be £10. A bench width of 3 ft to 3 ft 6 in has been assumed and the lamp spacings quoted are expected to give similar average irradiance levels and comparable plant performance. Electricity costs are based on 1 p per kwh.

Table 1. Characteristics and costs of a range of lamp types suitable for supplementary lighting.

Lamp type	Lamp power (watts)	Assumed life (h)	Lamp spacing (feet)	Initial capital cost £ / ft	Running Costs pence per 1000h per ft		
					Lamp	Electricity	Total
MB	400	7,000	5	3.13	10	84	94
MBFR	400	7,000	5	2.10	15	84	99
HLRG[+]	400	7,000	5	2.40	19	84	103
MBI	400	5,000	6	5.19	32	71	103
MCFRE	4 x 125	7,000	8	2.66	5	69	74
SON / T[*]	400	5,000	8	4.85	40	55	95
HPS[†]	400	5,000	8	3.87	40	55	95
SOX	180	6,000	5	4.60	25	40	65

[+] with simple lampholder
[*] with separate ignitor
[†] with ignitor built into the lamp