Information

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Artificial Lighting

Until comparatively recently, the scarcity of natural light during the winter months was accepted with a certain degree of resignation by growers. A possible reason for this, paradoxically as it may seem, is the fact that light is the only growth factor that the grower does not have to pay for.

Knowledge of the influence of light upon plant growth and yield has considerably increased in recent years, while the development of new types of lamp and new growing techniques have made the use of artificial lighting for the irradiation of plants an economic proposition. This has enabled the commercial grower not only to increase the productivity of his enterprise in terms of both more and better plants and shorter cultivation times, but also to produce plants that can be made available for the market at the most favourable time.

BASIC CONCEPTS AND BACKGROUND INFORMATION

1. Light and life

One of the most characteristic properties of all living organisms is growth that is an increase in size and weight or in number. Growth requires the synthesis of new building elements, in the form of complicated organic substances, which is, to a large extent, an energy-consuming process. For nearly all living organisms, other than plants, the energy is obtained by breakdown of organic compounds, mainly sugars and fats, which, together with oxygen, form carbon dioxide and water. This process in accompanied by the release of a certain amount of energy. Metabolism thus depends upon an adequate supply of organic compounds and oxygen.

Both are supplied by green plants, because there the opposite process also takes place, that is organic compounds and oxygen are formed from carbon dioxide and water. It is this process, called photosynthesis, which needs light as the source of energy. All life on earth depends ultimately upon photosynthesis, directly in the case of green plants, as they are self-supporting so far as their energy needs are concerned, and indirectly in the case of man and animal life, as these depend upon the uptake of the substances originally formed by plants.

Since plant growth and food production are matters of primary importance for the maintenance of life, a great deal of research is directed towards improvements in agriculture and horticulture. Light, in addition to other environmental factors such as temperature, humidity, etc., has long been recognised as one of the crucial factors in plant growth, but it is only comparatively recently that an important part of agricultural research has been concentrated on the subject of plant irradiation by artificial light.

2. What is light?

Any source of electromagnetic radiation, whether it is the sun or an artificial radiator, emits a certain amount of energy consisting of electromagnetic vibrations. This radiation can be considered as a wave motion having a constant speed, but possibly varying in wavelength. The radiation from most sources usually contains a large number of different wavelengths.

The principal types of electromagnetic radiation can be arranged, in wavelength order, into what is called the electromagnetic spectrum. Not all wavelengths produce an impression of light on the human eye. Only the radiation emitted in the relatively narrow waveband between 380 nm and 780 nm (one nm or nanometre, is a millionth of a millimetre or 10^{-9} metre) has this effect and it is this visible part of the spectrum that is called light.

3. Light and plant growth

Three light-requiring processes govern plant growth:

- Photosynthesis
- Photomorphogenesis
- Photoperiodism

Of these, photosynthesis, in which radiant energy is converted into the chemical energy necessary for the synthesis of the organic components from which a plant is built up, is the most important as it is essential for the growth of the plant.

Photomorphogenesis is the formative effect of light on plants. Plants grown exclusively under red light look spindly and have small leaves, which appears to be the result of a lack of blue light. The amount of blue light necessary to prevent this abnormal growth is so small, however, that even the contribution from weak daylight through the glass of a greenhouse will normally suffice.

The process of photoperiodism is also influenced by the wavelength of the light. The red/far-red part of the spectrum is responsible for the phytochrome reaction, which determines whether the plant remains in the vegetative state or develops towards the generative state. Incandescent lamps are commonly used in horticulture for this purpose.

4. Daylight versus artificial light

The lower quantity of light (down to 1/10 of that during the summer) is due to the considerably shorter length of the days combined with lower light intensity caused by the low-lying sun and frequent cloud cover. Under these circumstances, light is definitely a limiting factor, and if we require unhindered growth, we have to add an extra amount of light energy.

The total daily quantity of radiation that the earth receives from the sun can be expressed as intensity (energy per area) multiplied by time. This quantity is referred to as radiation quantity, light quantity and daily quantity, and is usually expressed in joules per cm^2 (J/cm^2).

5. Artificial light for controlling plant growth

From the point of view of illumination, as opposed to plant irradiation, the effectiveness of a lamp is determined by two factors. Firstly, by the proportion of the electrical energy it converts into radiant energy, in the visible part of the spectrum (roughly between 400 and 700 nm). Secondly, it distributes this radiant energy over the visible spectrum.

But the human eye and plants are not equal in their sensitivity to different wavelengths of light. To show the effect of radiation of different wavelengths on plant growth, a plant sensitivity curve is required. As photosynthesis plays the main part in plant growth, it seems reasonable to choose the photosynthesis action spectrum for this purpose. In a photosynthesis spectrum, the amount of carbon dioxide fixation by a plant is determined as a function of wavelength.

The second misconception is that for plant growth a lamp should have a spectral energy distribution that has the same form as the plant sensitivity curve.

6. Terms and units used in plant irradiation and lighting

Table 1

The relationship between comparable radiometric and photometric terms and units			
Radiometric (radiant) quantity		Photometric (luminous) quantity	
Term	Unit(s)	Term	Unit(s)
Radiant energy	joule (J) watt-second (Ws)	**Luminous energy**	lumen-second (lm.s)
Radiant flux	joule per second (J/s) watt (W)	**Luminous flux**	lumen (lm)
Irradiance	watt per square metre (W/m^2) milliwatt per square (mW/m^2)	**Illuminance**	lumen per square metre (lm/m^2) lux (lx)
Radiant efficiency	milliwatt per watt (mW/W) per cent (%)	**Luminous efficacy**	lumen per watt (lm/W)

The most suitable unit for practical purposes for expressing the energy requirement of a specific plant species is the irradiance expressed in milliwatt per square metre (mW/m^2). It is an exact measure of the total quantity of energy in the wavelength band 400 – 900 nm received by the plants.

Applications

1. To supplement daylight in greenhouses in order to increase the irradiance level for photosynthesis.
2. To increase the effective day length (photoperiodism).
3. As a substitute for daylight in growing rooms where plants are grown for commercial purposes under tightly controlled environmental conditions.
4. As a substitute for daylight in laboratories where plants are grown for research purposes.
5. For decoration.

7. Lighting for photosynthesis

For at least four, or possibly six, months of the year in such areas, plant growth is restricted by the shortage of light. In these areas the use of artificial light to supplement the daylight will thus improve plant growth.

Light apart, the growth and flowering of plants is also influenced by a number of other factors, such as the type of amount of the fertiliser used, ambient and soil temperature, humidity, etc. Given that these factors are favourable and constant, the rate of growth in given time is dependent upon the total amount of radiant energy that is received by the plant during that time, on the condition that the dosage is spread over long periods.

The effectiveness of artificial light, however, depends not only on the level and the length of time for which it is applied, but also on the degree to which it supplements the daylight: in other words, on the relative contribution of artificial light to the total amount of radiation received by the plant.

A given amount of artificial light can be provided either in the form of a high irradiance level for a short time, or as a lower level for a longer time. Experiments have shown that the latter method generally yields the better results.

Supplementary lighting applied in the correct way will stimulate assimilation and thus growth, resulting in a shorter production cycle, stronger and healthier plants, and earlier flowering. Also, the effects of variations in natural light intensity will be counteracted, with the benefit that cultivation time and crop quality become more predictable.

Typical irradiation levels for photosynthesis between 5,000 and 20,000 mW/m^2, which generally calls for the use of high-intensity discharge lamps. These light levels apply to supplementary light only and any available daylight comes on top of them. Due to the consequences of the law of diminishing results in relation to electricity costs it is advisable to turn off the lights when daylight reaches a level two times that of supplementary lighting. The effect of daylight on a plant is much greater than that normally given out by high-pressure sodium lights. We would therefore say that daylight has a conversion factor of 4 and high-pressure sodium of 2.3. For example a high-pressure sodium instillation producing a light level of 2,600 lx, or 2.3 times 2,600, equals 6,000 mW/m^2. This would be switched off when the daylight level reaches 12,000 mW/m^2. As the conversion factor of daylight is 4, this corresponds to 3,000 lx actual daylight measured inside the glasshouse.

8. Lighting for photoperiodism

Artificial lighting can be relatively simply and cheaply used to extend the day length. This is because the irradiance needed amounts to a mere 150-400 mW/m². Its use to manipulate the point of time of flowering is particularly attractive to the commercial grower.

Two methods offer themselves: the day can be lengthened by switching on the artificial lighting at dusk for a certain period or, alternatively, the night can be 'broken up' by switching on the lighting for short periods. The latter method is often favoured, because of its economy in terms of energy usage. Day lengthening is the more effective method, however, if artificial lighting for photosynthesis is also provided.

Where this is the case, florescent tubes will generally be employed. But where artificial light is used exclusively for photoperiodic purposes, where the irradiance level needed is low and short, it is quite acceptable to use incandescent lamps.

A refinement of the method of photoperiodic lighting by night breaks is the so-called 'cyclic lighting'. In this, the night breaks are further divided into periods of light and darkness, where light is provided during 20 to 30 per cent of the time. On the condition that these short cycles are repeated at least every 30 minutes, the plant will react as if the lighting were being provided continuously (a phenomenon attributable to the so-called after-effect). A method often adopted is to divide the greenhouse into three to five sections, which are lighted in turn during the night breaks so as to spread the electrical load more evenly. Cyclic lighting gives excellent results with plants such as strawberries and chrysanthemums.

9. Artificial light as a substitute for daylight

The substitution of artificial light for daylight is found in so-called growing rooms where all natural daylight is excluded. For this technique to be economically viable, the plants being grown must fulfil one or more of the following requirements:

- Need only a low level of irradiance under natural conditions, as will be the case with seedlings and cuttings;
- Need a relatively high temperature, difficult to obtain economically in a greenhouse with its poor insulation;
- Grow rapidly, and so occupy space for only a short period;
- Are small;
- Have a high value, either intrinsically, or by virtue of being grown out of season;
- Are required to be grown during winter months or according to a strict time schedule;
- Are required to be grown in a well-insulated room on account of extreme climatic conditions.

10. Decorative plant lighting

The lighting of house plants and flowers in the home, offices, commercial buildings, flower shops, etc. serves not only as an additional decorative element, but is also used as a means of maintaining and promoting growth.

Decorative plant lighting mostly takes the form of accent lighting, using concentrated light sources. Incandescent lamps can be used for this supplementary lighting, but if necessarily in combination with daylight or other artificial light sources, like fluorescent tubes, to avoid elongation. Care must be taken to see that the incandescent lamps are mounted at a sufficient distance from the plants so that the radiant heat does not dry out the plants, thereby shortening their life. This type of light is usually carried out by single lamps, such as SL*R "Agro", or layers of lamps over whole areas, such as SON-T.

11. Lamps

Table 2 shows the radiation characteristics of the lamps used in horticulture as supplied by Philips Lighting.

Table 2

Lamp type[1]		Rated wattage (ballast included) W	Luminous flux lm	Conversion factor[2] mW/lm	Radiant flux mW	Radiant efficiency mW/W	Economic life hrs	Recommended application
Incandescent								
GLS	150 W	150	2,220	4.2	9,320	62	1,000	Photoperiodism, decorative and display
Pressed-glass	150 W	150	1,600	4.2	6,720	45	2,000	Decorative and display
Fluorescent								
'TL'D 33	58 W	70	4,800	2.9	14,000	194	7,500	Photoperiodism and photosynthesis
'TL'D 82	58 W	70	5,200	2.9	15,000	208	7,500	Photoperiodism, photosynthesis and display
'TL'D 83	58 W	70	5,400	2.9	15,600	216	7,500	Photoperiodism, photosynthesis and display
'TL'D 84	58 W	70	5,400	2.9	15,600	216	7,500	Photoperiodism, photosynthesis and display
'TL'D 93	58 W	70	3,750	3.4	12,750	177	7,500	Photoperiodism, photosynthesis and display
'TL'D 94	58 W	70	3,750	3.5	13,100	182	7,500	Photoperiodism, photosynthesis and display
Compact gas-discharge								
SL*	25 W	25	1,200	2.8	3,360	134	6,000	Photoperiodism and display
SL*R "Agro"	18 W	18	900	2.8	2,500	139	6,000	Photoperiodism and display
PL 18/82	18 W	25	1,200	2.5	3,020	122	7,500	Decorative and display
PLC 18/82	18 W	25	1,200	2.5	3,080	124	6,000	Decorative and display
High-pressure mercury								
HPL-N	400 W	423	23,000	2.9	66,700	158	12,000	Photosynthesis
HPL-Comfort	50 W	56	2,000	3.1	6,200	111	8,000	Photosynthesis and display
Metal halide								
HPI-T	400 W	413	31,500	2.8	88,200	214	8,000	Photosynthesis and display
Blended light								
MLL	250 W	250	5,500	3.3	18,150	73	6,000	Decorative and display
MLL	100 W	100	1,100	3.3	3,630	36	6,000	Decorative and display
MLR	160 W	160	3,100	3.0	9,300	93	6,000	Decorative and display
High-pressure sodium								
SON-H[3]	350 W	373	34,500	2.3	79,350	213	8,000	Photosynthesis
SON-T	400 W	436	47,000	2.3	108,100	250	12,000	Photosynthesis

[1]) Types in this table represent a selection from a broad product range.
[2]) Conversion factor of sunlight: 4.0.
[3]) Direct replacement for HPL-N 400W.

Metal-Halide lamps
The white light of these lamps is very similar to the human eye and close to daylight. It is quite understandable that during the starting period of grow light this lamp type was a favoured light source. However, the rising field costs and relatively short life span of the lamp have now priced it out of the market. The light output during its lifetime reduces my 30% or more, making it necessary to install at least 25% more fittings than can be derived from the initial light output published by the manufacturers. However, metal halide lamps will be used for special applications where light levels of 7,000 to 9,000 lx are required.

High-pressure Sodium lamps
Because the high-pressure sodium lamp is the most efficient with an acceptable spectrum that is available its application becomes more and more universal. The facts that it also has a superior life span and the drop in light output is slight have played a decisive role in this choice of lamp. The somewhat unnatural yellowish colour has proved to be of no detrimental value to the quality of the crops and growing results are excellent.

Fluorescent lamps
The efficiency of these lamps with their excellent colour rendition is not enough to attain commercially acceptable results for large-scale glasshouse use. Their bulk takes away so much of the available daylight that production is often hampered beneath them. Application of these lights, therefore, only takes place where growing room conditions are necessary.

Compact gas discharge
SL* lamps are compact gas-discharge lamps containing a built-in miniature ballast and an E27 screw cap. They can replace incandescent lamps in a number of applications, such as photoperiodic lighting and in pendant luminaries for decorative plant lighting. They more than double the radiant efficiency whilst extending the average life of the lamps from 1,000 to 6,000 hours.

12. Plant Examples

Azalea indica
Supplementary lighting is not used very often on Azalea. On rooting cuttings however a lighting of 6,000 mW/m² during 18 hours a day gives a very good result. The rooting proceeds faster and more uniformly. Also during the forcing period lighting gives good results. In this case 3,000 mW/m² and a day length of 16 hours is used.

Camellia japonica
For better plant quality and early flowering it is lighted. A lighting level of 4,500 mW/m² gives good results. Because Camellia is day length sensitive, a day length of only 14 hours should be applied.

Nursery stock
The rooting of cuttings and the growth of young stock plants is highly stimulated by supplementary lighting. Also dormancy is often suppressed by lighting. In all cases supplementary lighting is done at a level of 7,500 mW/m² for a day length of 24 hours, both during rooting and in the nursery.

Good results have been obtained with species like Aucuba, Calluna, Erica, Euonymus, Ilex, Picea, Prunus, Pseudotsuga, Salix, Sorbus, Spiraea, Tsuga and Viburnum.

Garden or bedding plants
In order to be able to sell flowering garden plants early in the spring, the young plants are lighted during the winter. Often a level of 6,000 mW/m² is applied for a day length of 16 hours. Examples are: Aster, Impatiens, Pelargonium, Petunia, Tagetes and Zinnia.

General indications of these may be used with supplementary lighting. In most cases where supplementary lighting is to be used on crops that are not mentioned these indications may be used in order to get an idea of the levels to start with. These figures are based on lx values using high-pressure sodium lamps.

3,000 mW/m² (1,300 lx): Lighting after flower induction during the latter part of the cultivation period; growing of plants that need long days, given a marginal growth stimulus at the same time.

4,500 mW/m² (2,000 lx): Cultivation of production plants from planting out until harvest; young plants in the nursery after spacing out.

6,000 mW/m² (2,600 lx): Rooting and young plants before spacing out, production plants that need more light.

7,500 mW/m² (3,250 lx): Rooting nursery stock and nursing young plants that need much light.

9,000 mW/m² (4,000 lx): Cultivation of expensive plants; nursery stage of fast and programme crops; special effects for Lilies etc.

As far as the time of turning on and off is concerned, please note the following points for those cases in which it is not possible to light 24 hours per day:

- Avoid frequent turning on and off. You expensive equipment will last longer that way, especially the lamps.
- The plants profit more from longer hours of light, in winter light saturation is not easily reached.
- Some plants do not endure 24 hours of light per day, many however do!
- If your crop does not endure continuous light, do not let the necessary dark period fall in the middle of the night, but immediately after natural daylight has gone. In this way less turning on and off is necessary.

Luminaires (High-pressure sodium lamp types)
Several different designs of luminaires are available for nursery use. They principally come in two basic designs; those where head room is restricted, often called low bay units or winged fittings, and those where head room is not restricted, called high bay units or inverted "U". The characteristics of these two luminaires is important to achieve suitable light levels and an even spread of light over the crop. If follows that no matter how well a lighting scheme is designed it will still tend to consist of pools of bright light beneath each lamp. The design, however, is important to ensure these pools of light are as even as possible.

Luminaire details
Philips SGR 200 (low bay unit) has the following characteristics:

Table 3

Irradiance	Illuminance	Minimum mounting height	Minimum area/luminaire	x/y co-ordinate ratio
mW/m^2	lx	m	m^2	R
6,000 12,000 18,000 24,000	2,500 5,000 7,500 10,000	1.0 0.8 0.6 0.4	6.7 5.0 3.4 1.7	2.28 x 2.94 2.0 x 2.54 1.63 x 2.09 1.15 x 1.48

Philips SGR 103 (high bay unit) has the following characteristics:

Table 4

Irradiance	**Illuminance**	**Minimum mounting height**	**Minimum area/luminaire**	**x/y co-ordinate ratio**
mW/m^2	lx	m	M^2	R
6,000 12,000 18,000 24,000	2,500 5,000 7,500 10,000	2.0 1.3 1.1 1.0	6.8 5.0 3.4 1.7	2.9 x 2.3 2.5 x 2.0 2.06 x 0.65 1.45 x 1.66

From this information you can determine the height of the lamp above the crop and the distance between the luminaires in the row and between rows.

Conversion between light units

Light source		**MW/lm**
Daylight		4
GLS	Tungsten filament	4.3
MCF Warm White	Fluorescent	2.7
MCF White	Fluorescent	2.7
MB/U	HP Mercury vapour	2.5
MBF	HP Mercury vapour	2.7
MBFR/U	HP Mercury vapour	3.1
HLRG	HP Mercury vapour	3
MBI	Mercury halide	2.9
SON/T	HP Sodium	2.4
SOX	LP Sodium	2.1

The following manufacturers and suppliers provide lighting equipment:

Brinkman UK Ltd
Heron Buildings
Plaxton Bridge Road
Woodmansey
East Yorkshire
HU17 0RT
Tel: 01482 842123

Fargro Ltd
Toddington Lane
Littlehampton
West Sussex
BN17 7PP
Tel: 01903 721591

Thermoforce Ltd
Wakefield Road
Cockermouth
Cumbria
CH13 0HS
Tel: 01900 823231

Van Vliet Automation Ltd
42 Stockbridge Road
Elloughton
Brough
East Yorkshire
HU15 1HN
Tel: 01482 668676

Hotbox international Ltd
Unit 1
236 Main Road
Newport
Brough
East Yorkshire
HU15 2RH
Tel: 01430 444040

Sunlight Systems Ltd
Unit 27
Crawford House
West Avenue
Wigston
Leicester
LE18 2FB
Tel: 0116 2810881

Hortisystems UK Ltd
Sylvan Nurseries
West Chiltington Road
Pulborough
West Sussex
RH20 2PR
Tel : 01798 815815