Optimizing the light

Interlighting, LEDs and new coverings are contributing to optimize conditions

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A device for measuring diffuse radiation.
PHOTOS COURTESY NICOLAS CASTILLA

ABSTRACT

■ Light has to be optimized, as well as other growing factors, for an optimum greenhouse production.

Available sunlight must be preferred for a sustainable production. In the south of Europe, relevant attention has been paid to greenhouse design improvement for solar radiation transmission enhancement. New greenhouse covering materials are contributing to optimize the available sunlight. The use of highly diffusing cover materials is spreading.

However, adding artificial light can be necessary, in some cases, to ensure a year-round production. The crop energy efficiency under artificial lighting can be further improved.

New artificial lighting systems, such as interlighting and light emitting diodes (LED), have been developed and are being investigated.

INTRODUCTION

■ Except for some special cases (such as for crops of low light requirements), the objective of maximizing the solar radiation inside the greenhouse must be pursued, especially during the months in which radiation is a limiting factor of the production, as long as the costs do not hinder the primary goal of achieving a good profitability of the greenhouse (Castilla, 2007). The clear and documented relation between light and yield makes it a priority to maximize light. As natural light is freely received from the sun, solar radiation must be maximized.

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For an optimum quantitative and qualitative production, light intensity and spectrum as well as photoperiod must be adapted to the plant requirements. The optimization should include other growing factors, like temperature, humidity and CO2.

All the possibilities for optimizing the sunlight penetration into the greenhouse must be considered, adapting greenhouse coverings, screens and screening strategies, using photo-selective plastic film, coatings or netting, and optimizing the light use efficiency of crops, by manipulating the crop itself or adapting the growing system. However, adding artificial light can be necessary, in some cases, to ensure a year-round production (Hemming, 2010).

This paper presents a short general outlook on the current situation of the use of light in the European greenhouse industries and its optimization.

OPTIMIZING SOLAR RADIATION USE: LIGHT INTENSITY

■ The main factors affecting the solar radiation transmitted inside a greenhouse are the type of structure, the shape and slope of the greenhouse roof, its orientation with respect to the sun, the location of the greenhouse equipment (due to the shadows they generate), the characteristics of the solar radiation (direct and diffuse components) and of the cladding material (glass, plastic film, rigid panel . . .) (Castilla, 2007).

The transmission of solar radiation through the plastic or the glass of a greenhouse will depend on the incidence angle of the solar rays (direct radiation conditions) on the greenhouse cover (angle of the solar rays and a perpendicular line to the cover) (Castilla, 2007). The lower the angle of incidence is obtained, the higher the transmitted radiation (radiation that passes through the plastic film or glass and enters the greenhouse.

The architectonical shapes of the roof and the greenhouse orientation must tend to optimize the incidence angle, without losing sight of other relevant aspects of the design (cladding surface and its influence on the energy balance, resistance to the wind, volume and greenhouse dimensions, ventilation area, etc. . . .), which may limit its economic viability. Diffuse radiation (also known as hemispherical radiation) comes from all directions from the sky. Therefore, the architectonical shape of the greenhouse roof has much less influence on the greenhouse transmission of radiation when solar radiation is diffuse.

On a sunny day, most solar radiation is direct radiation, while on an overcast day, solar radiation is diffuse. For an average year, solar radiation in the Netherlands is around 30 per cent direct and 70 per cent diffuse, while in

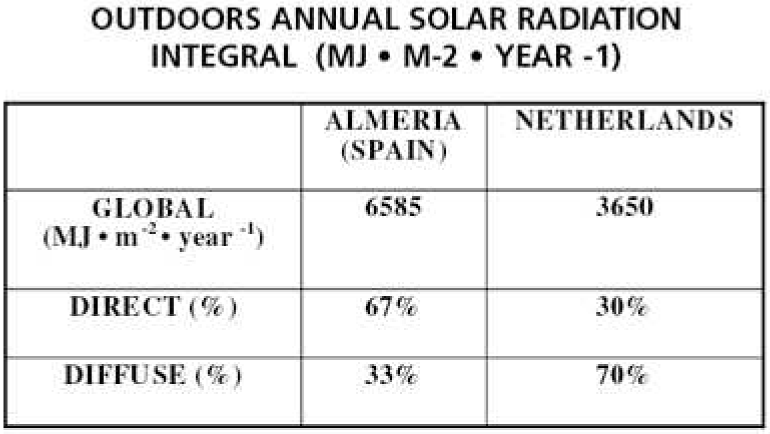
Almeria (south of Spain) the solar radiation is around 67 per cent direct and 33 per cent diffuse.

“Global greenhouse radiation transmissivity” is the proportion of solar radiation that is transmitted inside a greenhouse.

Increasing global radiation transmissivity in Mediterranean greenhouses, especially during the low radiation season, has been reported to be one of the most effective methods to raise yields and quality of the produce (Castilla, 2007). The east-west orientation improves radiation transmission in the low radiation season, as compared with the north-south orientation, but generates radiation transmission differences between the different zones of the greenhouse (Papadakis et al., 1998; Soriano et al., 2004-a,b). However, these transmission differences are mitigated due to the increasingly used greenhouses of higher roof slopes (and less wide spans) and the utilization of light-diffusing covering materials (Castilla, 2007).

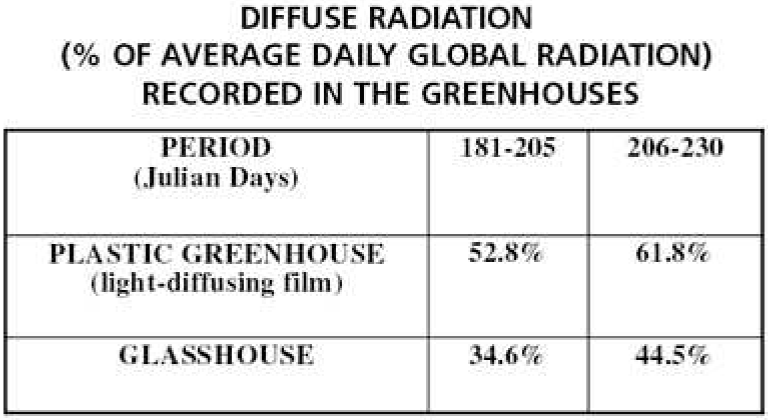
NEW COVERING MATERIALS INCREASE LIGHT INSIDE THE GREENHOUSE

■ The use of new covering materials can allow growers to increase the light inside the greenhouse; examples include white, low-iron glass, new plastic films like EFTE, or new nano-sized surface structures (Hemming et al., 2010).



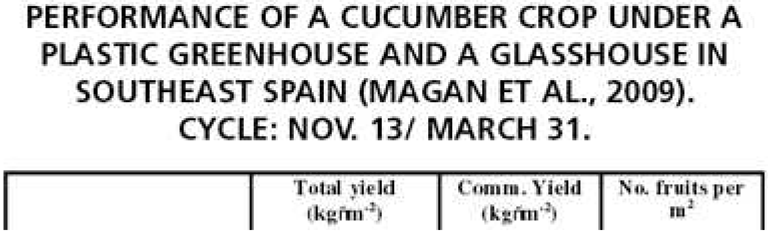
OUTDOORS ANNUAL SOLAR RADIATION INTEGRAL (MJ • M-2 • YEAR -1)

	ALMERIA (SPAIN)	NETHERLANDS
GLOBAL (MJ • m^{-2} • year $^{-1}$)	6585	3650
DIRECT (%)	67%	30%
DIFFUSE (%)	33%	70%



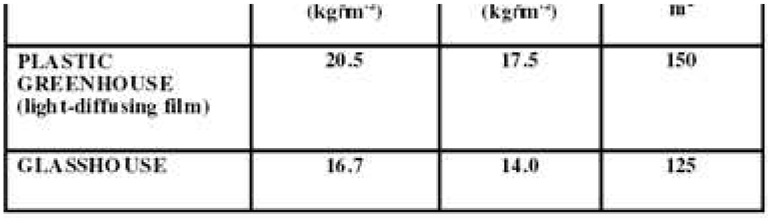
DIFFUSE RADIATION (% OF AVERAGE DAILY GLOBAL RADIATION) RECORDED IN THE GREENHOUSES

PERIOD (Julian Days)	181-205	206-230
PLASTIC GREENHOUSE (light-diffusing film)	52.8%	61.8%
GLASSHOUSE	34.6%	44.5%



PERFORMANCE OF A CUCUMBER CROP UNDER A PLASTIC GREENHOUSE AND A GLASSHOUSE IN SOUTHEAST SPAIN (MAGAN ET AL., 2009). CYCLE: NOV. 13/ MARCH 31.

	Total yield (kg/m^{-2})	Comm. Yield (kg/m^{-2})	No. fruits per m^{2}



	(kg/m^{-2})	(kg/m^{-2})	m^{-2}
PLASTIC GREENHOUSE (light-diffusing film)	20.5	17.5	150
GLASSHOUSE	16.7	14.0	125

In lower latitudes, such as in the south of Europe, especially during periods of high radiation, plants often have to be protected against too much light, to improve fruit quality (avoid sunburn of fruits by direct radiation), or to reduce too high temperatures. Screens, temporary coatings and nettings are used to decrease light intensity, shading the greenhouse.

Greenhouse shading limits the solar irradiance and, consequently, the heat load and air temperature. Any decrease of photosynthetic active radiation (PAR) might be expected to decrease crop productivity (Gonzalez-Real and Baille, 2006). External mobile shading is much more efficient, because of the ability to control the shade, but it is expensive to install. Cover whitening, the use of a white application on the exterior cover to increase reflectivity and reduce transmission, is an inexpensive method to reduce, in warm countries, the heat load during the high solar radiation season. This practice limits the solar radiation transmission with positive effects on microclimate, reducing air VPD and temperature. Whitening does not affect greenhouse ventilation, while internal shading nets do, and whitening increases the fraction of diffuse irradiance within the greenhouse, which is known to enhance the plant radiation use efficiency (Castilla and Montero, 2008).

In the north of Europe, in periods of low radiation and low outdoor temperatures, screens are mainly used for energy saving. If semi-transparent screens are installed, they can also be used for light regulation. The strategy followed for movable screens is important, to achieve a proper energy saving without affecting greenhouse production (Hemming, 2010). Model simulations with transparent energy screens have shown that keeping the energy screen more closed during the morning and evening hours, up to an outdoors radiation level from 50 to 150 W m-2, can be of interest (Dieleman and Kempkes, 2006).

MINIMIZE LOSSES CAUSED BY STRUCTURAL ELEMENTS

■ Summarizing, to maximize solar radiation, the losses due to structural elements and equipments must be minimized. The site selection, orientation, shape and slope of the roof and cladding material characteristics are primary aspects to capture the maximum possible radiation inside the greenhouse, keeping in mind that the best technical solution is not always the most economically suitable (Castilla, 2007). The use of screens, temporary coatings and nettings for greenhouse shading are effective and widely used, specially in lower latitudes.In addition, a proper management of the greenhouse must maintain a high light transmission. To clean the cover, limit the condensation of the water in the inner surface of the cover (as it reduces the transmissivity) by means of a good climate control (which limits high humidity content in the air) or using drip irrigation and/or mulching (which reduces water evaporation from the soil), orient the crop rows north-south, paint the structural elements in white and use white mulch to reflect the radiation, are some of the measures that may help to achieve the goal of maximizing the solar radiation available for the crop in the greenhouse.

DIFFUSE RADIATION

■ Diffuse radiation represents an important fraction of solar radiation entering greenhouses (Baille and Tchamitchian, 1993). Increasing the relative fraction of diffuse radiation in green-houses contributes to higher radiation uniformity within the greenhouse (Kurata, 1992) and to yield increase, due to higher radiation efficiency (Baille, 1999; Castilla, 2007).

The spreading use of highly diffusing cover materials in the Mediterranean area contributes to limiting direct solar radiation inside the greenhouse, increasing the diffuse fraction of radiation (Cabrera et al., 2009).

Crops such as fruit and vegetables with a high plant canopy utilize diffuse radiation better than direct radiation, as diffuse radiation penetrates the middle layers of a high-grown crop and results in a better horizontal radiation distribution in the greenhouse (Hemming et al., 2008).

The high solar radiation, especially in autumn and winter, in the Mediterranean area is associated with the large number of clear days, in which direct solar radiation prevails over diffuse radiation (Castilla, 2007).

There is a general trend to use covering materials which diffuse the incoming light, without relevant reduction of transmission values, therefore contributing to improve crop production and radiation use efficiency (Heuvelink and Gonzalez-Real, 2008; Hemming et al., 2008).

The higher proportion of diffuse radiation in a plastic greenhouse covered with light-diffusing plastic film is, as compared with a conventional glass-covered greenhouse, the main factor influencing yield, higher in the plastic house than in the glasshouse, in the South of Spain (Magan et al., 2010).

Papadopoulos and Hao (1997) have reported higher cucumber yields in a double cover polyethylene film greenhouse, that can be attributed to the increase in diffuse radiation fraction of sunlight, as compared with a glasshouse in Canada, with great savings in initial investment and energy use.

An increasing interest in developing in the Netherlands as new glass panels of high light-diffusing characteristics have appeared in recent years (Hemming et al., 2010).

LIGHT QUALITY

■ Changes in light spectrum influence shoot elongation, formation of side shoots, leaf area and leaf thickness, germination processes, tropisms, flowering induction and development, colour of flower and leaves, among many other effects (Hemming, 2010).

Light spectrum can be manipulated with plastic films, screens and nettings. Different coloured nets are now commercial, for specific physiological responses and some traditional shading nets, like the black types, are being replaced with other coloured nets (screens) like red, yellow or pearl colours (Shahak, 2008).

Photoselective plastic films have been developed to obtain a desired photomorphogenetic response (Castilla and Montero, 2008). The photoselective plastic films that alter the ratio “red-far red” (R/FR) of incoming light, affecting plant morphogenesis, or reduce crop diseases (Botrytis), or modify the behavior of insects (influencing their vision) by blocking certain wavebands of the solar radiation spectrum (UV blocking), or limit the sun energy load (NIR, near infra-red, blocking), are now commercial (Heuvelink and Gonzalez-Real, 2008). Other special covering materials, like fluorescent and coloured plastic films, can be of interest assuming that they do not reduce PAR transmission, but their use is limited.

Magan et al. (2010) have reported a higher proportion of diffuse light in a plastic house (around 53 per cent) than in a glasshouse (around 35 per cent) in the south of Spain, illustrating the diffuse radiation enrichment effect of the light-diffusing plastic cover (Cabrera et al., 2009).

LIGHT USE EFFICIENCY

■ Light use efficiency is the parameter that determines how much production is realized per unit of intercepted light (Heuvelink et al., 2010).For example, the fresh yield of tomato fruit per unit of light received at the top of the plant (kg · MJ-1), is dependent on many factors, such as leaf area index, carbon dioxide level, harvesting index (partitioning) or fruit dry matter content (Heuvelink et al., 2010).

Intercepted light is higher in diffuse radiation conditions, due to the non-directional characteristic of diffuse light, allowing a better penetration of light inside the canopy, reaching the medium and lower leaves levels in a well-developed crop. When direct radiation prevails, the upper leaves are shadowing the lower leaves, whose photosynthetic capacity is sub-utilized, and light use efficiency is lower, as compared with diffuse radiation conditions (Castilla, 2007).

USE OF ARTIFICIAL LIGHT

■ The traditional way of using artificial light, for complementing natural light, in the north of Europe is the use of high-pressure sodium lamps (HPS), as they have high energy efficiency and an acceptable spectrum (light quality). In fully artificial light conditions, uncommon in most commercial cases, other lamp types are frequently used (fluorescent tubes).

A major challenge for the use of artificial lighting is the reduction of energy use and costs. Reductions are possible by increasing the light use efficiency (LUE) of the crops, optimizing light duration and intensity, interplanting, changing plant densities, and changing the shape of the growing system, as well as an adaptation of the crop conditions and management [more efficient genotypes, other planting dates, etc.] (Hemming, 2010).

Energy efficiency can be increased by using interlighting or more efficient lamps, as it is expected from light emitting diodes (LED) in the future.

Interlighting induces a better LUE, giving part of the light to the middle/lower parts of the plant canopy. Combining interplanting with top-lighting is a promising solution, but further developments are needed (Hemming, 2010).

In general, it can be concluded that interlighting offers potential for energy saving and higher LUE of crops for the future (Hemming, 2010). The small size of LEDs and “their cold light” make them most suitable for interlighting.

LIGHT EMITTING DIODES

■ Light-emitting diodes (LED) can allow, in the future, the reduction of high energy consuming systems, such as HPS lamps.

LEDs influence light quality besides light intensity. As it has been recently stated by Hemming (2010), the optimum light spectrum per crop, when LEDs are applied as supplemental light in greenhouses, are not well known especially at a canopy level, that differs from the leaf level. LEDs can improve energy efficiency in the future, when proper developments are run.

LEDs are different from HPS. They emit a mono wavelength light colour that causes, next to photosynthetic effects, photomorphological responses. LEDs cause, at the same light intensity, a lower crop head temperature compared to HPS, since they do not emit any infrared radiation that contributes to increasing crop temperature.

LEDs influence transpiration and probably water and nutrient uptake.

Growers still need to “learn to grow with LED” (Hemming, 2010). Improvements of LEDs can be expected in the future. Until now, the energy efficiency of LED systems used in practice did not reach the level of HPS; however, they are close to that. Energy efficiency can be expected to increase more in the future and costs will probably decrease. It will be necessary to optimize the use of LEDs within the total horticultural system.

CONCLUDING REMARKS

■ In order to optimize light, as well as light intensity, daily light integral, light spectrum and the desired photoperiod have to be considered. Light is only one of the production factors, and has to be optimized together with all other growth factors like temperature, humidity, and CO2, nutrients and water.

Since natural sunlight and energy is available without any costs, it has to be preferred above artificial light.

In the south of Europe, relevant attention has been paid to greenhouse design improvement for solar radiation transmission enhancement. New greenhouse covering materials, such as the light-diffusing plastic films, are contributing to optimize the available sunlight.

Adding artificial light can be necessary, in some cases, to ensure a year-round production. Crop energy efficiency under artificial lighting can be further improved. New artificial lighting systems, such as interlighting and light emitting diodes (LEDs), have been developed and are being investigated.

In order to reach a high sustainable and economic beneficial production, the factor light has to be integrated and optimized within the total horticultural system.

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